EGAS MONIZ SCHOOL of HEALTH & SCIENCE | ESCOLA SUPERIOR DE SAÚDE EGAS MONIZ

ESCOLA SUPERIOR DE SAÚDE EGAS MONIZ

MESTRADO EM FISIOTERAPIA

THE EFFECTS OF NECK PAIN ON POSTURAL CONTROL VARIABILITY IN DENTAL MEDICINE STUDENTS: A LONGITUDINAL STUDY

Trabalho submetido por **Sofia de Oliveira Vieira**
para a obtenção do grau de Mestre em Fisioterapia Neuro-Musculoesquelética

julho de 2025, Monte da Caparica

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Trabalho orientado por
Professor Doutor Manuel João Videira da Silva Barbosa de Almeida

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Resumo

A dor cervical é uma queixa comum entre estudantes de medicina dentária, resultante das posturas mantidas durante a prática clínica, podendo comprometer o controlo postural. No entanto, os efeitos longitudinais da dor cervical sobre a variabilidade do controlo postural permanecem pouco explorados. Este estudo teve como objetivo analisar, ao longo de três semestres de prática clínica, como a presença de dor cervical influencia a variabilidade do controlo postural em estudantes de medicina dentária. Quarenta e quatro estudantes participaram inicialmente do estudo, sendo divididos em dois grupos: com e sem dor cervical, com base no Nordic Musculoskeletal Questionnaire. A avaliação foi realizada através de uma plataforma de forças, em oito condições posturais distintas considerando as componentes anteroposterior e mediolateral. A variabilidade do controlo postural foi quantificada utilizando a SampEn, calculada com recurso a um script personalizado em MATLAB. Os dados foram analisados através de um modelo linear de efeitos mistos, considerando como variáveis fixas o grupo, o tempo, a posição postural, a rotação cervical e a condição visual. Os resultados revelaram que, ao longo do tempo, o grupo com dor cervical apresentou uma diminuição progressiva da variabilidade postural, refletindo um padrão mais rígido, especialmente nas tarefas mais desafiantes, como a posição tandem com olhos fechados. Estes achados sugerem que a dor cervical afeta negativamente a capacidade de adaptação postural dos estudantes, evidenciando a necessidade de estratégias preventivas no contexto académico e clínico.

Palavras-chave: dor cervical; control postural; estudantes de medicina dentária; variabilidade; entropia.

Abstract

Neck pain is a common complaint among dental medicine students, resulting from sustained postures during clinical practice and potentially compromising postural control. However, the longitudinal effects of neck pain on postural control variability remain underexplored. This study aimed to analyze how the presence of neck pain influences postural control variability in dental medicine students over the course of three semesters of clinical training. Forty-four students initially participated in the study and were divided into two groups— with and without neck pain— based on the Nordic Musculoskeletal Questionnaire. Postural control was assessed using a force platform across eight distinct postural conditions, considering both anteroposterior and mediolateral components. Postural control variability was quantified using SampEn, calculated via a customized MATLAB script. Data were analyzed through a linear mixed-effects model, with fixed factors including group, time, postural position, cervical rotation, and visual condition. Results revealed that, over time, the neck pain group showed a progressive reduction in postural variability, reflecting a more rigid control pattern, especially under more demanding tasks such as tandem stance with eyes closed. These findings suggest that neck pain negatively affects the students' ability to adapt posturally, highlighting the need for preventive strategies in academic and clinical settings.

Keywords: neck pain; postural control; dental students; variability; entropy

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List of abbreviations

AP- Anterioposterior

BMI- Body Mass Index

CG- Control Group

CoP- Center of Pressure

ML- Mediolateral

NMQ- Nordic Musculoskeletal Questionnaire

NP -Neck Pain

NPG- Neck Pain Group

SampEn- Sample Entropy

SD – Standard Deviation

Introduction

Musculoskeletal disorders, especially neck pain (NP), with a mean lifetime prevalence of 48.5% in general population, is a significant occupational health issue in the field of dentistry beginning in university student population with a prevalence estimate of 51% of musculoskeletal disorders in neck (Almeida et al., 2023; Amaral et al., 2018; Kawtharani et al., 2023).

In the professional world, dentists are a susceptible group with many predisposing factors for neck pain. Their profession requires them to work bent towards the patient and assume this position (with cervical flexion, inclination and rotation of the trunk, shoulder elevation, and incorrect positioning of the lower limbs) throughout the procedure, overloading the cervical spine (Fernandez de Grado et al., 2019)

Dentists, in their precise maneuvers with small instruments within the constrained oral cavity, expose their musculoskeletal system to potentially damaging forces. This extended exposure to such conditions poses health risks, with chronic neck pain being a potential outcome. Notably, these health risks manifest early during dentists' university clinical practice, establishing groundwork for the condition to develop and persist over time (Samoladas et al., 2018).

In line with these observations, examining postural control in individuals with and without neck pain highlights showed that individuals experiencing neck pain demonstrate compromised postural control compared to their asymptomatic counterparts. Multiple factors contribute to this impairment, involving the impact of pain on local nociceptors and mechanoreceptors, both at the spinal cord and within the central nervous system (Amaral et al., 2018).

In postural control, the precise functioning of the proprioceptive system in the neck is especially important for maintaining the intact sense of joint position and control of head and cervical spine movement. Considering that the neck muscles have a high density of muscle spindles, especially in the suboccipital region, and that cervical sensory afferents strongly influence the vestibular and visual systems to control postural stability, impaired neuromuscular function of the neck muscles can significantly impact deficits in postural control. (Mendes-Fernandes et al., 2021; Mendes Fernandes et al., 2023; Paulus & Brumagne, 2008).

In the study of postural control, the degree of pressure movement on a force platform is employed to identify postural instability, where increased movement suggests greater instability.

This conventional approach, however, overlooks the intricacies of postural patterns, failing to consider that upright posture is rarely an isolated task but rather integrated into broader task goals, such as those encountered in the field of dentistry. Examining a specific moment in isolation makes unraveling the causes of musculoskeletal conditions challenging (Harbourne & Stergiou, 2009; Stergiou, 2004).

Nonlinear methods are essential for analyzing postural control, as they capture the complexity and temporal structure of motor variability, features that linear measures fail to address. While linear methods quantify the magnitude of oscillation, nonlinear approaches reveal dynamic and subtle adaptations within biological systems. Based on complex systems theory, it is now recognized that the structure of postural variability must be considered in stability assessments. A random pattern of the Center of Pressure (CoP) shows no attraction to specific regions in the state space, exhibiting resistance to perturbations but limited adaptability. In contrast, a chaotic pattern combines stability and variability, with attraction to certain regions and greater adaptive capacity—characteristics associated with the complexity of healthy systems. Conversely, movement variability below the optimal level reflects a rigid pattern, in which biological systems become overly stable yet insufficiently adaptable (Harbourne & Stergiou, 2009; Søndergaard et al., 2010; Stergiou et al., 2006; van Emmerik et al., 2002).

The relationship between motor control and neck pain has been scarcely explored, and existing cross-sectional studies have not demonstrated consistent associations. By examining the variability of postural control and its influence, longitudinally, in dental medicine students initiating their clinical practice, it is possible to analyze the long-term effects of clinical practice associated to neck pain in postural control and subsequently gain a better understanding of its causes (De Zoete et al., 2021).

Observations from the early stages of clinical training suggest that students with neck pain have lower variability of postural control (Almeida et al., 2024). However, it remains unclear how these patterns evolve throughout the course of clinical training. Therefore, we hypothesized that dental students experiencing neck pain during clinical practice would exhibit a progressively more rigid temporal structure of postural control over time.

Methodology

Study Design

This study integrates a longitudinal study of a PhD investigation that observed postural control variability among dental students with and without neck pain during their first two years of clinical practice, in 4th and 5th years of studies, during three semesters of clinical practice, in a force platform of Egas Moniz's clinic in February 2025. This is an observational study design.

All participants who met the eligibility criteria made 3 visits to the laboratory. The participants signed the informed consent (Appendix 1) and answered the Nordic Musculoskeletal Questionnaire (NMQ) (Appendix 2). To ensure methodological rigor and transparency, the study design and reporting were conducted in line with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement.

Participants

Eligibility Criteria

This study included male and female dental students who voluntarily participated in the research. Participants were allocated into two groups based on their responses to the Nordic Musculoskeletal Questionnaire (NMQ) regarding the presence of neck pain within the past seven days. Asymptomatic students were assigned to the control group (CG), while those reporting symptoms were assigned to the neck pain group (NPG). Group allocation remained concealed until the completion of the assessment.

The inclusion criteria were (i) being dental student in 4th and 5th undergraduate; (ii) exposed to clinical practice regularly (iii) being available to answer the NMQ; (iv) signing the written informed consent. Exclusion Criteria were: (i) having systemic diseases such as fibromyalgia, diabetes, rheumatoid disease, or uncontrolled hypertension (ii) previous or current diagnosis of acute vestibular diseases and having neurological, cognitive or psychotic disorders (iii) over 30 years of age (iv) students with ongoing musculoskeletal disorders especially on the neck.

Recruitment Plan

The study enlisted dental students in their 4^{th} and 5^{th} at Egas Moniz School of Health and Science. Participants were contacted via email, inviting them to take part in the research. Those who opted to participate were then provided with an NMQ to complete, through a link, which allowed them to be grouped.

Sample Size Calculation

The statistical analysis to be carried out presupposed the prior definition of the desirable number of participants based on what was necessary for the study of postural control. The minimum number of participants in the study was 55, calculated using GPower software considering α=0.05 (5% chance of Type I error) and a minimum of 1-β = 0.80 (Power of the sample) with an effect size of d=0.7 (Bonilla-Barba et al., 2020).

Data Collection

This data collection took part in a previously initiated project, and the analysis was supported by data collected at the beginning of the 4th year and after one semester of clinical practice, for comparison purposes. For data collection, participants visited Egas Moniz Physiotherapy Clinic.

The testing began after signing the informed consent and after confirming that there was no clinical history that constituted exclusion criteria. These measurements were taken with the participants wearing their usual clothes. Body mass and height were measured in kg and cm using an electronic scale and a measuring tape, respectively. Then, the body mass index (BMI) was calculated by dividing the mass of the participants by the square of their height in meters. Then, the participants answered NMQ which includes questions about the presence and intensity of musculoskeletal symptoms, such as pain or discomfort, in various body regions, including the neck, facilitating their grouping into those with and without neck pain based on eligibility criteria (Mesquita et al., 2010).

Subsequently and after removing footwear, participants stepped into the force platform with their arms by their side in the middle of the platform, in a standardized position, 2 m away from the wall. The measurement of CoP displacement in a tri-axial force platform was done (Bertec Corporation, Columbus, Ohio) at 500 Hz. CoP data was identified from the ground reaction forces in different positions, such as narrow and tandem stance with eyes open and closed in neutral position and 60º left cervical rotation, totaling 8 collection positions. Each position was assessed for 45 seconds with the CoP in the x and y axes, allowing evaluation of mediolateral and anteroposterior deviations. Leftward head rotation was chosen to reflect the standard clinical posture of students, who predominantly operate from the patient's right side. Each position was tested in a randomized sequence. Whenever the participant lost his balance, changed the posture stance or if excessive movement of any part of their body, like arms and trunk the trial was discarded and repeated. Subsequently, the data obtained was processed with the Bertec Acquire software.

For the analysis of CoP oscillations, data were initially acquired at a sampling frequency of 1000 Hz and subsequently downsampled to 50 Hz, to optimize data processing and reduce high-frequency noise. This sampling rate was selected based on previous studies indicating that the relevant CoP signal components are primarily concentrated below 10 Hz. Furthermore, spectral analysis of the raw data revealed maximum frequencies of 14.91 Hz in the AP axis and 11.51 Hz in the ML axis. Thus, the choice of a 50 Hz sampling rate ensures compliance with the Nyquist criterion, which states that the sampling frequency must be at least twice the maximum frequency present in the signal (Delgado-Bonal & Marshak, 2019; Gow et al., 2015).

Data Analysis

One of the most used techniques for assessing human balance is static posturography, which involves measuring the displacement of the CoP during quiet, upright standing. The CoP is defined as and represents a weighted average of all pressures applied to the surface in contact with the ground. It is typically recorded using a force platform, which generates a two-dimensional time series representing the CoP trajectory along the anteroposterior (AP) and mediolateral (ML) axes (Noamani et al., 2023).

Entropy refers to the degree of disorder and randomness in a system and can be interpreted as a measure of complexity and unpredictability. Sample Entropy (SampEn) allows for the estimation of the randomness of a time series without prior knowledge of the data-generating source. It demonstrates relative consistency and lower dependency on data length (Chen et al., 2009; Delgado-Bonal & Marshak, 2019; Montesinos et al., 2018).

SampEn values were computed using a custom script developed in MATLAB R2023b (The MathWorks Inc., USA). The analysis was based on a data length (N) of 2250 points, corresponding to a 45-second signal sampled at 50 Hz, with a pattern length (m) set to 2 and a tolerance (r) of 0.2. After collecting and processing the data, it was exported to the Jamovi (v 2.4.8) (Fox, 2020; Lenth, 2023; The Jamovi project, 2023; Team, 2022).

Statistical Analysis

Descriptive statistics were calculated to characterize the sample, including count, mean, standard deviation, median, minimum, maximum, and range. The outcome variable, entropy, was summarized across all experimental conditions using descriptive analysis performed in R (v.4.4.2).

To assess the effects of evaluation moment, group, stance, axis, cervical rotation, and visual condition on postural entropy, a linear mixed-effects model was fitted using the lmer function from the lmerTest package. The entropy values were log10-transformed to satisfy model assumptions.

Fixed effects included all main factors and their interactions, and a random intercept was included for each participant to account for within-subject variability across repeated measures.

Model assumptions were evaluated using residual diagnostics generated with the resid_panel function from the ggResidpanel package, to detect deviations from normality and potential outliers. Estimated marginal means were computed for combinations of evaluation moment and group, stratified by stance, axis, rotation, and visual condition, using the emmeans function.

Pairwise comparisons were performed with Tukey adjustment to test differences between groups across time points. Estimated means were visualized using ggplot2, with results displayed separately for each stance condition (Goode & Rey, 2022; Kuznetsova et al., 2017; Lenth, 2023; Rich, 2020; Team, 2018; Wickham, 2009).

Results

Figure 1 presents the flow of participants throughout the three assessment moments of the study.

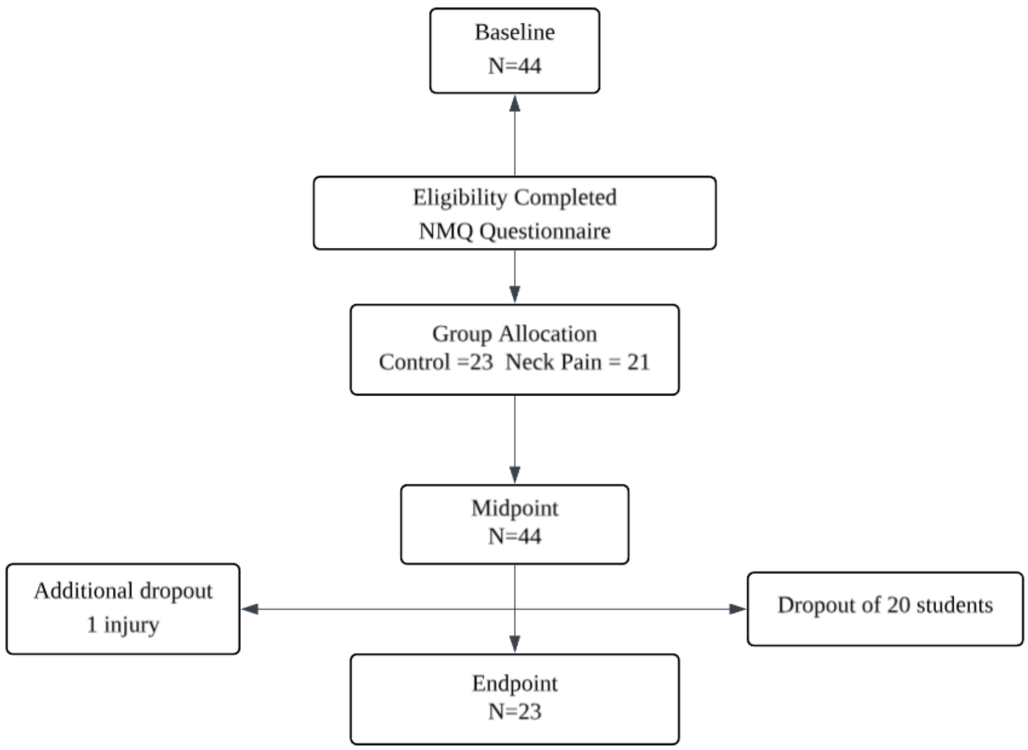

Figure 1- Participant flowchart across the three assessment moments

At the beginning of the study, the sample consisted of 44 participants, of whom 68.2% were female (n = 30) and 31.8% male (n = 14), with a mean age of 22.34 ± 2.06 years and a mean body mass index (BMI) of 21.76 ± 3.07 kg/m². Three data collection sessions were conducted: one at baseline, one at the end of the first semester, and one at the end of the second semester. Of the initial 44 participants, 20 dropped out of the study and 1 sustained an injury that prevented participation in the final assessment, resulting in a final sample of 23 participants. Of these, 60.9% were female (n = 14) and 39.1% male (n = 9). Sociodemographic information of the participants is presented in Table 1.

Table 1 – Sociodemographic characteristics of the participants.

	Overall (N=44)		Control (n = 23)		Neck pain (n = 21)	
	Mean±SD	[Range]	Mean±SD	[Range]	Mean±SD	[Range]
Age (years)	22.3 ± 2.06	[20–30]	21.8 ± 1.92	[20–29]	22.9 ± 2.10	[21–30]
Height (m)	1.70 ± 9.20	[1.54– 1.92]	1.72 ± 0.08	[1.58–1.88]	1.68 ± 0.10	[1.54–1.92]
Body mass (kg)	63.4 ± 11.1	[46–88]	63.3 ± 10.65	[46–86]	63.5 ± 11.38	[47–88]
BMI (kg/m²)	21.9 ± 3.00	[16.9–35.3]	21.2 ± 2.11	[17.6–24.6]	22.4 ± 3.82	[16.9–35.3]
Sex % (n)	Female 68.2% (30) Male 31.8% (14)		Male 43.5% (10) Female 56.5% (13)		Male 19.1% (4) Female 80.9% (17)	

Note. BMI = Body mass index, SD = standard deviation

Between-group analysis did not reveal significant differences at any time point or SampEn condition, except for the tandem stance, eyes closed, and no cervical rotation, in the AP component during the midpoint assessment (after one semester of clinical practice) [$p < 0.001$]. Detailed results of the between-group analyses are presented in Table 2.

Table 2. Comparison over three semesters of clinical practice between groups.

			Baseline			Midpoint			Endpoint		
Stance	**Position**	**Axis**	**Control Mean ± SD**	**Neck Pain Mean ± SD**	***p***	**Control Mean ± SD**	**Neck Pain Mean ± SD**	***p***	**Control Mean ± SD**	**Neck Pain Mean ± SD**	***p***
Narrow	0º OE	AP	0.14±0.01	0.17±0.01	0.245	0.16±0.01	0.15±0.01	0.996	0.15±0.02	0.15±0.02	1.000
		ML	0.17±0.01	0.21±0.02	0.358	0.19±0.01	0.21±0.02	0.862	0.18±0.02	0.19±0.02	0.994
	0º CE	AP	0.12±0.01	0.14±0.01	0.366	0.12±0.01	0.14±0.01	0.688	0.14±0.01	0.12±0.01	0.910
		ML	0.16±0.01	0.19±0.02	0.687	0.18±0.01	0.20±0.02	0.997	0.17±0.02	0.18±0.02	0.999
	60º OE	AP	0.17±0.01	0.17±0.01	1.000	0.15±0.01	0.15±0.01	1.000	0.13±0.01	0.14±0.01	0.999
		ML	0.17±0.01	0.19±0.02	0.904	0.19±0.01	0.20±0.02	0.979	0.17±0.02	0.19±0.02	0.988
	60º CE	AP	0.12±0.01	0.13±0.01	0.994	0.13±0.01	0.14±0.01	0.999	0.10±0.01	0.13±0.01	0.601
		ML	0.16±0.01	0.17±0.01	0.979	0.16±0.01	0.17±0.01	0.977	0.16±0.02	0.17±0.02	1.000
Tandem	0º OE	AP	0.26±0.02	0.29±0.02	0.944	0.27±0.02	0.24±0.02	0.915	0.28±0.03	0.20±0.02	0.181
		ML	0.24±0.02	0.26±0.02	0.982	0.27±0.02	0.28±0.02	0.992	0.27±0.03	0.33±0.03	0.794
	0º CE	AP	0.20±0.02	0.21±0.02	0.997	0.24±0.02	0.15±0.01	<0,001*	0.26±0.03	0.23±0.02	0.968
		ML	0.23±0.02	0.27±0.02	0.734	0.28±0.02	0.24±0.02	0.668	0.26±0.03	0.24±0.02	0.990
	60º OE	AP	0.32±0.02	0.25±0.02	0.180	0.31±0.02	0.31±0.03	1.000	0.36±0.04	0.27±0.03	0.307
		ML	0.27±0.02	0.29±0.02	0.998	0.28±0.02	0.27±0.02	1.000	0.31±0.03	0.29±0.03	0.998
	60º CE	AP	0.25±0.02	0.24±0.02	1.000	0.24±0.02	0.20±0.02	0.426	0.32±0.03	0.23±0.02	0.168
		ML	0.24±0.02	0.24±0.02	1.000	0.26±0.02	0.25±0.02	1.000	0.26±0.03	0.24±0.02	0.996

*Note. 0º = cervical neutral position; 60º = 60 degrees of cervical left rotation; AP anterior–posterior, ML medial-lateral, CE Closed eyes, OE Open eyes, p p-value, SD Standard deviation; * = p-value <0.05*

Within group comparisons were conducted across different time points. From the first to the second data collection, at the end of the first semester, a decrease in variability was observed in the pain group in the tandem stance, eyes closed, and with no cervical rotation, in the AP component [$p = 0.005$], that has not been seen in CG. From the second to the third collection, a decrease in variability was again found in the pain group under the same conditions, tandem stance, eyes closed, no cervical rotation, AP component [$p = 0.002$].

Unlike the previous comparisons, within group analysis between the first and third data collections revealed significant differences in SampEn in the pain group in the tandem stance, eyes open, and no cervical rotation, in the AP component [$p = 0.029$]. Detailed results of the within-group analyses are presented in Table 3. This information is provided in greater detail in Appendix 3.

Table 3. Comparison over three semesters of clinical practice within groups

			Control						Neck pain					
Stance	**Position**	**Axis**	**Baseline** Mean ± SD	**Midpoint** Mean ± SD	**Endpoint** Mean ± SD	***p*** Baseline vs Midpoint	***p*** Baseline vs Endpoint	***p*** Midpoint vs Endpoint	**Baseline** Mean ± SD	**Midpoint** Mean ± SD	**Endpoint** Mean ± SD	***p*** Baseline vs Midpoint	***p*** Baseline vs Endpoint	***p*** Midpoint vs Endpoint
Narrow	0° OE	AP	0.14±0.01	0.16±0.01	0.15±0.02	0.513	0.969	0.513	0.17±0.01	0.15±0.01	0.15±0.02	0.764	0.731	1.000
		ML	0.17±0.01	0.19±0.01	0.18±0.02	0.930	1.000	0.930	0.21±0.02	0.21±0.02	0.19±0.02	1.000	0.942	0.943
	0° CE	AP	0.12±0.01	0.12±0.01	0.14±0.01	1.000	0.766	1.000	0.14±0.01	0.14±0.01	0.12±0.01	0.998	0.484	0.721
		ML	0.16±0.01	0.18±0.01	0.17±0.02	0.663	0.998	0.663	0.19±0.02	0.20±0.02	0.18±0.02	0.999	0.997	0.975
	60° OE	AP	0.17±0.01	0.15±0.01	0.13±0.01	0.939	0.228	0.939	0.17±0.01	0.15±0.01	0.14±0.01	0.738	0.279	0.935
		ML	0.17±0.01	0.19±0.01	0.17±0.02	0.918	1.000	0.918	0.19±0.02	0.20±0.02	0.19±0.02	0.991	1.000	0.991
	60° CE	AP	0.12±0.01	0.13±0.01	0.10±0.01	0.925	0.600	0.925	0.13±0.01	0.14±0.01	0.13±0.01	0.983	1.000	0.975
		ML	0.16±0.01	0.16±0.01	0.16±0.02	1.000	1.000	1.000	0.17±0.01	0.17±0.01	0.17±0.02	1.000	1.000	1.000
Tandem	0° OE	AP	0.26±0.02	0.27±0.02	0.28±0.03	0.997	0.982	0.997	0.29±0.02	0.24±0.02	0.20±0.02	0.551	0.029*	0.583
		ML	0.24±0.02	0.27±0.02	0.27±0.03	0.933	0.924	0.933	0.26±0.02	0.28±0.02	0.33±0.03	0.970	0.383	0.804
	0° CE	AP	0.20±0.02	0.24±0.02	0.26±0.03	0.374	0.210	0.374	0.21±0.02	0.15±0.01	0.23±0.02	0.005*	0.961	0.002*
		ML	0.23±0.02	0.28±0.02	0.26±0.03	0.200	0.890	0.200	0.27±0.02	0.24±0.02	0.24±0.02	0.910	0.924	1.000
	60° OE	AP	0.32±0.02	0.31±0.02	0.36±0.04	1.000	0.913	1.000	0.25±0.02	0.31±0.03	0.27±0.03	0.185	0.984	0.789
		ML	0.27±0.02	0.28±0.02	0.31±0.03	1.000	0.914	1.000	0.29±0.02	0.27±0.02	0.29±0.03	0.995	1.000	0.997
	60° CE	AP	0.25±0.02	0.24±0.02	0.32±0.03	1.000	0.216	1.000	0.24±0.02	0.20±0.02	0.23±0.02	0.365	0.999	0.787
		ML	0.24±0.02	0.26±0.02	0.26±0.03	0.973	0.996	0.973	0.24±0.02	0.25±0.02	0.24±0.02	0.999	1.000	0.996

*Note. 0º = cervical neutral position; 60º = 60 degrees of cervical left rotation; AP anterior–posterior, ML medial-lateral, CE Closed eyes, OE Open eyes, p p-value, SD Standard deviation; * = p-value <0.05*

Discussion

Dental practice requires postures maintained with cervical flexion, trunk rotation, shoulder elevation and inadequate positioning of the lower limbs, resulting in overload of the cervical spine. These biomechanical demands contribute to the high prevalence of cervical musculoskeletal disorders observed in 51% of dental students during their clinical training (Almeida et al., 2023; Amaral et al., 2018; Fernandez de Grado et al., 2019; Kawtharani et al., 2023).

In line with these observations, an analysis of postural control in individuals with and without neck pain highlights a significant pattern. Individuals with neck pain show a decrease in postural control. The variability of postural control reflects the quality of postural control, as it reflects its fluctuations over time, and can be assessed through entropy, a non-linear measure. Several factors contribute to this change, including the impact of pain on local nociceptors and mechanoreceptors, both in the spinal cord and the central nervous system. In the facet joints and their muscles, the excitability of nociceptors can alter the sensitivity of muscle spindles and lead to a decrease in proprioceptive acuity (Amaral et al., 2018; Ruhe et al., 2011; van Emmerik et al., 2002).

When studying the variability of postural control, different parameters can be analyzed, and the displacement of the CoP on a force platform is one of the parameters that allows postural instabilities to be identified. In the light of the Optimal Movement Variability theory proposed by Stergiou et al., (2006), entropy, which quantifies the predictability and complexity of motor patterns, should fall within a range in which a system is stable enough to maintain postural control, but flexible enough to adapt to disturbances. Lower entropy values mean that the system is more aware of balance and consequently has more rigid motor strategies associated with pain or protection. Higher values mean a more disorganized system, associated with proprioceptive deficits, adopting random patterns (Almeida et al., 2024; Brumagne et al., 2008; Vaz et al., 2023).

Although this is a student population, it is recognized that musculoskeletal symptoms, particularly neck pain, can emerge early, even with a small number of hours of clinical practice. This process makes it particularly relevant to study this problem at an early stage in the professional career. With the aim of gaining a deeper understanding of this issue, this study investigated, in a longitudinal manner, the effects of neck pain on the complexity and variability of postural control in dental students over the course of three semesters. To this end, the variability of postural control was compared between students with and without neck pain in different postural conditions.

Our results showed that the variability of postural control changes over time, following the evolution of clinical practice, and these changes were significant in the symptomatic group, suggesting an impact of neck pain on the adaptability of postural control, confirming our hypothesis. There was a decrease in the variability of postural control in the group with pain compared to the group without pain, similar to what was analyzed in the study by Almeida et al., (2024), in which the group with neck pain adopted a more rigid pattern after just one semester of clinical practice, indicating that neck pain has an early influence on the efficiency of postural control. Our results corroborate the previous findings even though the sample of the present study was small in comparison.

These findings can be explained by the fact that pain affects the function of nociceptors and mechanoreceptors, altering sensory integration and leading to a more rigid and less adaptive control pattern, due to situations of greater postural challenge that limit the postural system's ability to adapt (Harbourne & Stergiou, 2009; Moseley & Hodges, 2006; Stergiou et al., 2006).

The cervical proprioceptive system plays a fundamental role in regulating postural control, contributing to the perception of joint position and the coordination of head and cervical spine movements. The cervical muscles, especially those in the suboccipital region, have a high density of neuromuscular spindles, which makes them highly sensitive to proprioceptive changes. The afferent signals from these muscles are integrated with the vestibular and visual systems and are decisive in maintaining postural stability (Mendes-Fernandes et al., 2021; Sung, 2022).

In the presence of pain, it is common to observe cervical neuromuscular dysfunctions, including abnormal activation patterns of the cervical flexor muscles, both superficial and deep, associated with strength and endurance deficits in the deep muscles. These alterations compromise motor control, cervical movement speed and postural awareness (Childs et al., 2008; Chiu & Lo, 2002; Schomacher et al., 2012; Vikne et al., 2013).

In addition, chronic pain is often associated with central sensitization processes, characterized by a reduced threshold for pressure pain and changes in pain modulation in the central nervous system. This can include increased pre-synaptic inhibition of muscle afferents and interference in the modulation of neuromuscular spindles, resulting in prolonged response latencies and disturbances in postural control. Considering the extensive anatomical and functional interconnections between the cervical spine and the vestibular, visual and central nervous systems, it is plausible that the alterations in balance associated with cervical dysfunction are the result of abnormal sensory afferents. These dysfunctional signals can conflict with information from the visual and vestibular systems, creating an imbalance in multisensory integration and compromising the effectiveness of postural control (Alahmari & Reddy, 2024; Mendes Fernandes et al., 2023; Quek et al., 2014; Ruhe et al., 2011)

Considering these neurophysiological alterations, and since pain influences the efficiency of the proprioceptive system, this information seems to justify the more rigid pattern presented in the group with pain, resulting in an inability to adjust and coordinate cervical movements and an inability to be aware of joint position.

As expected, the most significant results were seen in the AP component, considered to be the most demanding direction in conditions of a reduced base of support. In this postural configuration, maintaining stability requires motor control strategies characterized by high-frequency but low-amplitude oscillations of the CoP. Individuals with cervical dysfunction tend to have greater difficulties in adopting comfortable and effective postures and may have a reduced perception of postural instability in contexts of increased demand. Abnormalities in the ML direction would be more consistent with the expected patterns for vestibular dysfunction (Field et al., 2008; Ruhe et al., 2011).

Visual deprivation, by reducing the availability of external sensory information, may accentuate dependence on more rigid and less adaptive motor strategies, especially in individuals with pain, when there are proprioceptive deficits, since this deprivation increases dependence on the proprioceptive and vestibular system. The Re-weighting process explains that when there is a lack of sensory information from vision, the system looks for vestibular and proprioceptive information to readjust, but when there are proprioceptive deficits, this readjustment is not possible. (Harbourne & Stergiou, 2009; Moseley & Hodges, 2006; Nishijima David L; Wisner, David H; Holmes, James F & Maxson & Mitchell, 2016; Stergiou et al., 2006).

This is consistent with our results, which showed a reduction in variability during visual deprivation in the neck pain group, suggesting a greater dependence on systems other than vision, but also demonstrating the limitations of the vestibular and proprioceptive systems, given that more rigid patterns were still adopted in the individuals with pain.

Regarding the reduction in the base of support, in the Tandem position, there is a greater proprioceptive demand, which requires greater sensory integration. In simple tasks, vision and the vestibular system can compensate for proprioceptive deficits, but with a postural challenge, such as the Tandem position, the deficit becomes more evident and can result in a more rigid pattern. In less demanding positions, such as Narrow, proprioceptive deficits can be easily compensated for with visual or vestibular information (Amaral et al., 2018).

NPG showed a progressive reduction in postural control variability from the beginning of the study to the end of the first semester, and again from the end of the first to the end of third semester. This trend was not observed in the asymptomatic group. The decrease in variability over time suggests a progressively more rigid postural control pattern, possibly associated with pain-induced impairment of proprioception quality, an increase in the number of weekly hours of clinical practice during the last semester, and the increased demands of procedures in the third semester and their repercussions on pain in terms of representation and characterization, developing an even more rigid pattern. This can be justified because the integration of information from the proprioceptive, visual, and vestibular systems is altered when chronic pain is present. In addition, there may be an increase in motor pattern rigidity due to muscle fatigue caused by more prolonged and intensive recruitment of the cervical muscles. This fatigue impairs the afferent pathways sending sensory feedback to the central nervous system. (Abdelkader et al., 2020)

Finally, a decrease in variability was detected in the group with pain, not observed in the group without pain, from the first collection to the end of the study, when visual information was removed. This result seems to suggest that individuals with neck pain are more dependent on vision to maintain postural stability. This can be explained by the fact that cervical mechanoreceptors establish connections with the vestibular, visual, and central nervous systems. When dependent only on the proprioceptive and vestibular systems, given visual deprivation, the group with pain reveals insufficient postural stability, since altered proprioception proves to be a central problem (Amaral et al., 2018; Mooti & Park, 2022).

However, this study has limitations that should be considered. The main limitation is the small size of the final sample, which is a consequence of the dropout rate during follow-up, which may compromise the generalization of the results. In addition, the tasks used to assess postural control were performed in static and laboratory settings, which do not fully reflect the complex and dynamic postural demands experienced by students during actual clinical practice. This limitation restricts the applicability of the results to functional scenarios that are more representative of professional practice.

Given these limitations, future research should focus on assessing the impact of preventive interventions, such as training programs, ergonomic strategies, or postural education, on the variability and complexity of postural control in students with neck pain. In addition, it is recommended that research be expanded to more realistic contexts, including simulated clinical tasks or practical situations, in order to accurately capture the demands of the professional environment. Studies with larger samples and real clinical context conditions may reinforce the robustness and applicability of the data obtained.

Conclusion

This longitudinal analysis, which analyzed the effects of neck pain on postural control variability in dental students, showed that pain is related to a reduction in entropy, especially when there is a greater sensorimotor challenge, tending towards a more rigid and less adaptive pattern of postural control variability. This reinforces the hypothesis that neck pain compromises the effectiveness of sensory integration and motor control mechanisms, leading to a decrease in postural adaptation capacity. The increased reliance on less flexible motor strategies in contexts such as visual deprivation and a reduced base of support illustrates the adaptive limitations imposed by pain and associated proprioceptive dysfunctions. These limitations and dysfunctions may impair motor performance and precision, potentially compromising the safety and overall quality of clinical procedures.

Despite the small sample size, the results offer a relevant insight into the effects of neck pain at an early stage during academic training, reinforcing the importance of early intervention strategies and indicating the need for future studies to promote improvements in the occupational health of these future dental professionals.

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Appendices

Appendix 1 – Informed Consent Form (in Portuguese)

Estudo epidemiológico de sintomas musculoesqueléticos em estudantes de Medicina Dentária

Exmo.(a) Sr.(a),

No âmbito do projeto de doutoramento em Motricidade Humana, na especialidade de comportamento motor, sob a coordenação do Professor Doutor Raúl Oliveira, solicita-se autorização para a participação no estudo com o título, Prevalência e fatores associados das disfunções músculo-esqueléticas em alunos de Medicina Dentária, realizado com voluntários do 4º e 5º ano do curso de Mestrado Integrado em Medicina Dentária, com o objetivo de investigar a prevalência e fatores de risco associados ao desenvolvimento de disfunções musculoesqueléticas, promovidos pela prática clínica em estudantes de medicina dentária ao longo de um ano curricular.

A participação neste estudo pressupõe o preenchimento deste questionário online em momentos distintos dos anos curriculares de 2023-2024 e 2024-2025. Este questionário permite a identificação e quantificação de sintomas decorrentes de disfunções musculoesqueléticas como a dor, desconforto ou dormência nas diferentes regiões do corpo.

A fase inicial servirá para caracterizar o participante relativamente a alguns fatores de risco conhecidos, e a segunda fase implicará o preenchimento do Questionário Nórdico Musculoesquelético.
A participação neste estudo é voluntária. A sua não participação ou desistência não lhe trará qualquer prejuízo.

Este estudo pode trazer benefícios como a identificação das disfunções musculoesqueléticas relacionadas com a prática clínica e os fatores de riscos associados ao seu desenvolvimento, permitindo o desenvolvimento de estratégias futuras de prevenção de lesões que terão influência direta na incidência destas disfunções ao longo da carreira de dentista.

A informação recolhida destina-se unicamente a tratamento estatístico e/ou publicação e será tratada pelos investigadores integrados no estudo. A sua recolha é realizada à luz do Regulamento Geral de Proteção de Dados, sendo mantido o anonimato de todos os participantes.

O preenchimento deste questionário confirma que o participante aceita os termos deste consentimento informado.

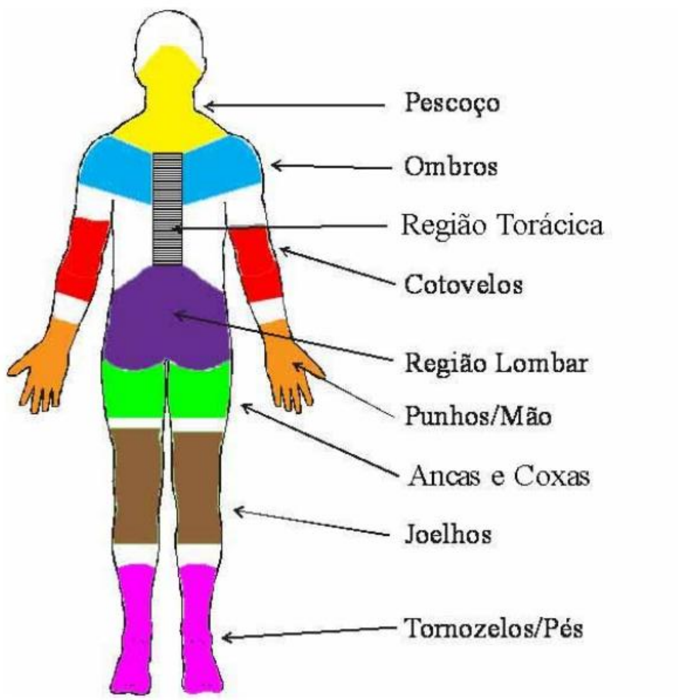
* Indica uma pergunta obrigatória

Appendix 2 – Nordic Musculoskeletal Questionnaire (Portuguese Version)

Questionário Nórdico Músculo-esquelético

Instruções para o preenchimento

- Por favor, responda a cada questão assinalando um "X" na caixa apropriada: ☒
- Marque apenas um "X" por cada questão.
- Não deixe nenhuma questão em branco, mesmo se não tiver nenhum problema em qualquer parte do corpo.
- Para responder, considere as regiões do corpo conforme ilustra a figura abaixo.



Versão portuguesa: Cristina Carvalho Mesquita
Contacto para autorização de utilização: ccm@estsp.ipp.pt

Questionário Nórdico Músculo-esquelético

Código:

Idade_____Data de nascimento____/___/___Sexo_________Data de hoje____/____/_____
Posto de trabalho________________________________Estado civil__________________
Nome____

	Responda, apenas, se tiver algum problema		
Considerando **os últimos 12 meses**, teve algum **problema (tal como dor, desconforto ou dormência)** nas seguintes regiões:	Teve algum problema nos **últimos 7 dias**, nas seguintes regiões:	Durante os **últimos 12 meses** teve que evitar as suas actividades normais (trabalho, serviço doméstico ou passatempos) por causa de **problemas** nas seguintes regiões:	
1. Pescoço? Não 1□ Sim 2□	2. Pescoço? Não 1□ Sim 2□	3. Pescoço? Não 1□ Sim 2□	4. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
5. Ombros? Não 1□ Sim 2□, no ombro direito 3□, no ombro esquerdo 4□, em ambos	6. Ombros? Não 1□ Sim 2□, no ombro direito 3□, no ombro esquerdo 4□, em ambos	7. Ombros? Não 1□ Sim 2□, no ombro direito 3□, no ombro esquerdo 4□, em ambos	8. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
9. Cotovelo? Não 1□ Sim 2□, no cotovelo direito 3□, no cotovelo esquerdo 4□, em ambos	10. Cotovelo? Não 1□ Sim 2□, no cotovelo direito 3□, no cotovelo esquerdo 4□, em ambos	11. Cotovelo? Não 1□ Sim 2□, no cotovelo direito 3□, no cotovelo esquerdo 4□, em ambos	12. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
13. Punho/Mãos? Não 1□ Sim 2□, no punho/mãos direitos 3□, no punho/mãos esquerdos 4□, em ambos	14. Punho/Mãos? Não 1□ Sim 2□, no punho/mãos direitos 3□, no punho/mãos esquerdos 4□, em ambos	15. Punho/Mãos? Não 1□ Sim 2□, no punho/mãos direitos 3□, no punho/mãos esquerdos 4□, em ambos	16. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
17. Região Torácica? Não 1□ Sim 2□	18. Região Torácica? Não 1□ Sim 2□	19. Região Torácica? Não 1□ Sim 2□	20. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
21. Região Lombar? Não 1□ Sim 2□	22. Região Lombar? Não 1□ Sim 2□	23. Região Lombar? Não 1□ Sim 2□	24. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
25. Ancas/Coxas? Não 1□ Sim 2□	26. Ancas/Coxas? Não 1□ Sim 2□	27. Ancas/Coxas? Não 1□ Sim 2□	28. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
29. Joelhos? Não 1□ Sim 2□	30. Joelhos? Não 1□ Sim 2□	31. Joelhos? Não 1□ Sim 2□	32. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima
33. Tornozelo/Pés? Não 1□ Sim 2□	34. Tornozelo/Pés? Não 1□ Sim 2□	35. Tornozelo/Pés? Não 1□ Sim 2□	36. Sem Dor 0 1 2 3 4 5 6 7 8 9 10 Dor Máxima

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Appendix 3 – Detail Results