



## OPEN The time-course changes in postural control variability between neck pain and asymptomatic dental students

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Changes in postural control associated with clinical practice or specific conditions such as the presence of neck pain remain unexplored in dental students. Therefore, this study aimed to explore the time-course changes in postural control complexity among dental students enrolled in clinical practice, comparing those with and without neck pain. We used an online Nordic Musculoskeletal Questionnaire for group allocation and center of pressure (CoP) oscillations with a tri-axial Bertec force plate. Baseline data were acquired from dental students with neck pain (NP) ( $n = 21$ ) and asymptomatic in a control group ( $n = 23$ ), before starting their clinical practice, and assessments were repeated after their first semester. CoP fluctuations were determined through the calculation of sample entropy. Both groups had similar postural control at baseline, but asymptomatic students exhibited more irregular CoP AP ( $p = 0.013$ ) and ML ( $p = 0.015$ ) oscillations, while students with neck pain showed a more rigid pattern ( $p = 0.004$ ) in the AP direction at the endpoint. Our results showed that dental students' postural control complexity decreased during the first semester of clinical practice. Over time, asymptomatic students exhibited more random postural control patterns, while students with neck pain demonstrated more rigid postural control during upright stance, indicating that postural control complexity differs between students with and without neck pain when exposed to clinical training.

**Keywords** Cervical pain, Dentistry students, Postural control, Complexity, Entropy

Dental professionals with static, asymmetrical postures and repetitive movements required in their work<sup>1–3</sup> are particularly susceptible to work-related musculoskeletal disorders (WMSDs). They are a prevalent health concern among dentists and dental students, with 95.8% of dentists reporting these issues at some point in their careers<sup>3</sup>. The onset of WMSDs can occur as early as the training years, with occurrence rates ranging from 44 to 93%<sup>1,2,4</sup>. These disorders are often exacerbated by the professional environment and working conditions<sup>3</sup>. In dental students, this physical strain primarily affects the neck, with a 12-month occurrence rate between 44% and 69%<sup>2,4</sup>. Although pain is a multifactorial phenomenon, each unique experience can induce specific motor responses and alterations<sup>5</sup>. To date, the association between motor control and neck pain has been minimally investigated, with cross-sectional analyses showing no clear links and few intervention studies providing inconsistent results over short follow-up periods, making it unclear if improved neck pain symptoms are related to changes in cervical motor control and if those changes vary over time<sup>6</sup>. Patients with neck pain demonstrate multiple sensorimotor impairments<sup>7,8</sup>, including reduced joint position sense<sup>9</sup> and increased postural sway<sup>10</sup>. The underlying mechanisms of these impairments are not well understood. However, a common feature of these sensorimotor impairments has been suggested to originate from disruptions in neck proprioceptive input to the central nervous system<sup>11,12</sup> and/or the central processing of this input associated with neck pain<sup>12</sup>. Neck muscles have abundant muscle spindles acting as proprioceptors, which are essential for maintaining postural control<sup>13</sup>. Effective neck proprioception is essential for optimal performance in specific tasks<sup>13</sup>. Adjustments in postural control can be triggered by erroneous proprioceptive signals, such as those resulting from sustained voluntary

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muscle contraction<sup>14</sup>, which are inherent to dental clinical practice. If impaired, this input can negatively influence postural control and balance<sup>12</sup>, as injuries causing weakness, sensory impairment, diminished joint range of motion, or changes in neural processing can affect the body's ability to maintain orientation in space<sup>15</sup>.

Postural control remains largely overlooked in dental students. Recent studies have primarily focused on ergonomic factors<sup>16,17</sup> and posture changes<sup>18,19</sup> without exploring the changes in postural control associated with clinical practice or specific conditions such as the presence of neck pain. Hence, there is a need for further explore the postural control and build knowledge on the motor control changes in dental students. A deeper understanding of postural control can be achieved through non-linear analysis of center of pressure (CoP) oscillations. It has been widely accepted that individuals with less CoP movement during a balance task exhibit better postural control<sup>20</sup>. However, Cavanaugh and colleagues, who investigated the temporal structure of CoP oscillations, argued that this assumption might be flawed<sup>15</sup>. This approach allows the study of control mechanisms that cannot be detected by simply evaluating the amount of CoP oscillations. By exploring the temporal structure of CoP oscillations, new information can be uncovered from the variability present in the CoP time series<sup>21,22</sup>. Over the past decade, various studies have revealed that the variability of the CoP location during quiet standing is not due to random error<sup>23</sup>. Instead, CoP oscillations, though appearing erratic and irregular, contain a 'hidden' structure or orderliness that emerges over time, presumably due to interactions among components of the postural control system<sup>15</sup>. Nonlinear analysis of these data can reveal richer and hidden characteristics of the time series that traditional linear methods overlook or cannot detect<sup>21,22</sup>. For further understanding, we must consider the optimal state of movement variability model<sup>24</sup>. Stergiou and colleagues in 2006 proposed that a healthy system has a chaotic structure representing a complex system with high levels of adaptability<sup>24</sup>. However, when these patterns shift toward randomness or become highly repeatable, the system's adaptability decreases<sup>25</sup>. This approach and the related experimental results have led to the development of a theoretical perspective on health and variability. Specifically, Stergiou and colleagues<sup>24</sup> proposed that a healthy system presents an optimal state of variability. Values above or below this optimal state indicate unhealthy states. Less than optimal movement variability indicates biological systems that are overly rigid and unchanging, while greater than optimal variability indicates systems that are noisy and unstable<sup>24</sup>. In both unhealthy states, the system has lower adaptive capacity and is more vulnerable to injury<sup>24</sup>. A rigid system can be linked to pain and fear-avoidance behaviors<sup>26,27</sup>. Conversely, noisy systems can be linked to lower proprioception<sup>28</sup>, altering the temporal structure of CoP oscillations, and resulting in a more random state. Both conditions could be observed in patients with neck pain and may contribute to decreased postural control complexity<sup>26–28</sup>. Measurement tools derived from nonlinear dynamics, which characterize the complexity of movement variability, provide useful means of testing these propositions<sup>24</sup>.

Workload position has been referred as an important factor in the occurrence of musculoskeletal symptoms in general, and specifically back pain among the working population<sup>29</sup>. Dentists often alternate between standing and sitting positions during their practice<sup>29</sup>. However, different specialties rely on varying durations of sitting or standing positions<sup>29</sup>. Although alternating positions is recommended for dentists to reduce fatigue by shifting muscular support to opposing muscle groups, thereby reducing musculoskeletal symptoms<sup>29–31</sup>, there is conflicting evidence regarding its effectiveness. It has been reported that there is no significant difference in neck symptoms between dentists who work exclusively in sitting positions and those who alternate between sitting and standing<sup>29,30</sup>. Conversely, other study has found that neck, shoulder, and back muscles experience higher muscular loads in a seated posture compared to a standing posture<sup>32</sup>. Nevertheless, seated postures have been reported to be more acceptable on average compared to standing postures, which often require greater adjustments<sup>31</sup>, a factor that could potentially be further exacerbated by postural control changes induced by pain.

Therefore, this study aimed to explore the time-course changes in postural control complexity among dental students enrolled in clinical practice, comparing those with and without neck pain. Our hypothesis was that postural control complexity would decrease in students with neck pain exposed to fifteen weeks of clinical practice while keeping stable in asymptomatic students. Building upon previous literature<sup>26,27</sup>, we anticipated that if pain influenced postural control, its complexity would decrease towards a rigid system. Conversely, if proprioceptive impairment affected postural control, we expected students to exhibit a noisier temporal structure, characterized by increased randomness.

## Materials and methods

### Study design

This longitudinal study is part of a comprehensive research project comprising three primary variables<sup>7,8</sup> and was approved by the Egas Moniz School of Health & Science Ethics Committee (CEEM-1122) in September 2022<sup>7,8</sup>. Anonymity and confidentiality of the data were strictly maintained in accordance with the European Union General Data Protection Regulation (GDPR), with data scheduled for deletion in April 2028. All methodologies adhered rigorously to the ethical principles outlined in the 1975 Declaration of Helsinki, as revised in 2008. The study design and reporting of findings followed the guidelines outlined in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement<sup>7,8</sup>.

### Participants

Fourth-year dental students enrolled in the master's degree program at Egas Moniz School of Health & Science, Portugal, voluntarily participated in this study<sup>7,8</sup>. Participants were assigned to one of two groups based on their responses about the presence of neck pain in the last 7 days in the Nordic Musculoskeletal Questionnaire (NMQ)<sup>7,8</sup>: the asymptomatic students for the control group (CG) and fourth-year students with neck pain (NP). The allocation of groups was concealed from all investigators and assessors by keeping the file hidden until the completion of the initial assessment. Inclusion criteria were: (i) students actively involved in clinical practice and

(ii) students from the 4th year. Exclusion criteria were: (i) students who had clinical practice before September 2023, (ii) over 30 years of age (iii) students with ongoing musculoskeletal disorders, (iv) inability or unwillingness to provide informed consent, (v) communication difficulties with investigators, (vi) major neurological disorders, (vii) dysfunctions of the central or peripheral nervous system, (viii) diagnosed schizophrenia, bipolar disorder or other psychotic disorders, (ix) alcohol or other substance abuse and (x) major depression<sup>7,8</sup>.

A minimum sample size of twenty participants per group was determined using GPower software, accounting for an  $\alpha$  of 0.05 (5% chance of Type I error), a minimum power (1- $\beta$ ) of 0.90, and a medium effect size of 0.269<sup>34</sup>.

### Procedure

Student's group allocation was conducted using an online form<sup>7,8</sup>, which included the informed consent and the NMQ<sup>7,8,34</sup>. The NMQ comprises 27 questions with binary yes-or-no responses. It includes three questions applied to nine anatomical regions: neck, shoulders, wrists/hands, upper back, lower back, hips/thighs, knees, and ankles/feet. The first question asks whether the respondent has experienced any trouble or pain in the last 12 months; the second inquiries about any work-related limitations in daily activities during the same period; and the third asks if any trouble or pain was experienced in the last 7 days<sup>34,35</sup>. The term "trouble" encompasses pain, discomfort, or aching<sup>35</sup>. To aid in the identification of body areas, the questionnaire includes a diagram highlighting all the relevant regions<sup>35</sup>. In the most recent version of the questionnaire, numeric pain scale was incorporated to classify the pain experienced in the last 7 days<sup>34</sup>. The questionnaire was administered twice: initially at the beginning of the academic year in September and again after 15 weeks at the end of the semester in December. Prior to participation, each student was required to read and digitally provide their consent before completing the questionnaire<sup>7,8</sup> and undergoing subsequent postural control assessment.

### Standing balance

After removing footwear, participants stepped onto a tri-axial force platform (Bertec Corporation, Columbus, Ohio) for standing balance assessment. Participants were instructed to stand in the middle of the platform, in a standardized position, 2 m away from the wall with their arms by their side. Measurements were made in eight different configurations, in narrow stance with parallel feet touching along their medial borders and tandem stance with right foot in front of left foot, with eyes open and closed, in neutral cervical position (0°) (facing the wall) and with 60° left rotation of the cervical<sup>36,37</sup>. The tandem stance with the right foot in front was selected to standardize the testing position and avoid pelvic rotation for the opposite side of the cervical rotation. Left rotation was chosen to align with the students' approach to their patients, as they always work from the right side of the patient. One trial of 45 s was conducted in each position in a random order. The trial started when the participant was stable in testing position and if a participant lost his balance, changed the trial stance or if excessive swaying of the contralateral limb, arms, and/or trunk occurred the trial was discarded and repeated.

### Data collection

CoP data was identified from the ground reaction forces at 1000 Hz in different positions, such as narrow and tandem stance with eyes open and closed in neutral position and 60° left cervical rotation, totaling 8 collection positions. Each position was assessed for 45 s with the CoP in the x and y axes, allowing evaluation of mediolateral and anteroposterior deviations<sup>36,37</sup>. Subsequently, the obtained data was processed with the Bertec Acquire software (Bertec Corporation, Columbus, Ohio).

### Data sampling

To analyze the oscillations of the CoP effectively, we downsampled CoP data by a factor of 20, resulting in a sampling frequency of 50 Hz<sup>38,39</sup>. Significant postural control information is contained within low frequency ranges around 10 Hz. To ensure the capture of all necessary data without introducing excessive noise, a higher sampling frequency, such as 50 Hz, is recommended<sup>38,39</sup>. To ensure the use of the adequate sampling frequency we calculated the maximum frequency of our data in the anterior-posterior (AP) (14.91 Hz) and medial-lateral (ML) (11.51 Hz) axis, confirming the 50 Hz a practical choice to capture these oscillations without aliasing issues<sup>38,39</sup>.

We used sample entropy (SampEn)<sup>40</sup> to determine the temporal structure of the CoP oscillations, for both the AP and ML components. SampEn measures the probability that short sequences of data points are repeated throughout a temporal sequence. The value of SampEn is always greater than or equal to zero. A time series with similar distances between data points results in a lower SampEn value, while large differences result in higher SampEn values. Thus, a perfectly repeatable time series has a SampEn value of zero, whereas a perfectly random time series has a SampEn value converging towards infinity. In this study, we used a pattern length (m) of 2, an error tolerance (r) of 0.2, and a data length (N) of 2250 data points (i.e., 50 Hz × 45 s) to calculate SampEn values. These parameters were used for the SampEn calculation<sup>41</sup>, which was performed using Matlab R2023b (The Mathworks Inc., USA) with a customized script.

### Statistical analysis

We used Jamovi (v 2.4.8) for the statistical analysis. Group data was analyzed with non-parametric test Chi-square for sex and the student's t-test for independent measures was applied to compare groups in age, height, body mass and body mass index. Prior to analysis, we assessed data distributions for normality and homogeneity of variances with Shapiro–Wilk and Levene's tests respectively. When those assumptions were met, we conducted a repeated measures Analysis of Variance (ANOVA) with group (Control vs. Neck Pain) as the between-subjects factor and time (baseline vs. 1st semester) as the within-subjects factor. When a significant interaction effect was found, we performed post-hoc comparisons using Tukey's honestly significant difference. For variables that did not meet the assumptions of normality, we employed non-parametric tests such as the Friedman test with

post-hoc comparisons using the Durbin-Conover method to identify the variables differing between time points within groups and the Mann-Whitney U test to compare differences between groups at each time point. The alpha significance level was set at 0.05.

## Results

Sixty students were invited to participate in our study. Of these, three declined. The remaining fifty-seven students agreed to participate and proceeded to data collection. During the study, thirteen participants (22.8%) dropped out after failing the second assessment, resulting in a final sample of forty-four participants. The participants were 68.2% women ( $n=30$ ) and 31.8% men ( $n=14$ ), with an average age of  $22.34 \pm 2.06$  years and an average body mass index (BMI) of  $21.76 \pm 3.07$  kg/m<sup>2</sup>. Detailed sociodemographic information on the participants is provided in Table 1.

Analysis of the NMQ data allowed for the allocation of participants into a CG ( $n=23$ ) and a NP group ( $n=21$ ). At baseline, no significant differences were found between groups in the AP nor in ML of CoP components SampEn except for the narrow stance without visual reference and neutral cervical position in the ML component (Fig. A.2) [ $U=137$ ,  $p=0.013$ ,  $r=0.370$ ].

Of the eight assessment positions, significant differences were observed only in the tandem stance with visual reference and neutral cervical position throughout the semester. Within the control group, a moderate effect size was found in the ML component over the semester (Figure A.4), [ $t(42) = -3.149$ ,  $p=0.015$ , Cohen's  $d = -0.48$ ]. Additionally, the SampEn in the AP component increased for the control group from baseline to the end of the semester (Fig. A.3) ( $p=0.013$ ), whereas the neck pain group showed a decrease in SampEn over the same period ( $p=0.004$ ).

Between groups analysis showed significant differences in the tandem stance with visual reference and neutral cervical position (Fig. A.3). The mean score in the AP component for the control group at the end of the first semester ( $M=0.26$ ,  $SD=0.09$ ) was significantly different from the Neck Pain group after the first semester ( $M=0.17$ ,  $SD=0.07$ ), with a moderate to large effect size, [ $U=110$ ,  $p=0.002$ ,  $r=0.466$ ]. Detailed results of the within and between group analyses are presented in Tables 2 and 3 and further detailed in supplementary material.

## Discussion

The demanding nature of dental students' educational path, which involves rigorous theoretical and practical training, examinations, and their relatively limited experience compared to seasoned dental professionals<sup>1,2</sup> is one of the explanations for their high prevalence of work-related musculoskeletal disorders. Cervical region has been identified as the anatomic region with the highest occurrence of work-related musculoskeletal disorders<sup>1,3</sup> during clinical training, despite their low accumulated clinical training hours, turning it into a major concern among these professional class and stake holders. Increased postural sway is a motor control impairment commonly observed in patients with neck pain<sup>10</sup>. However, its underlying mechanisms are not fully understood. A common feature of these sensorimotor impairments is their dependency on afferent somatosensory input from proprioceptors<sup>11</sup>. If impaired, this input can negatively influence postural control. Moreover, the recommendation for alternating positions to reduce musculoskeletal symptoms<sup>29-31</sup>, produced conflicting conclusions regarding its effectiveness. It has been reported that neck pain rates between dentists that alternate work positions and those who work in sitting position are similar<sup>29,30</sup> while other study has found that neck, shoulder, and back muscles experience higher muscular loads in a seated working posture compared to a standing posture<sup>32</sup>. However, standing postures often require greater adjustments<sup>31</sup>, a factor that could potentially be further exacerbated by postural control changes induced by pain. Exploring the standing postural control changes associated with these occurrence rates could provide new insights into the causes and consequences of this issue. Therefore, we aimed to investigate the time-course changes in postural control complexity among dental students during their first semester of clinical practice, comparing those with and without neck pain. Based on the premise that a healthy system is characterized by an optimal level of variability<sup>24</sup>, we hypothesized that postural control complexity would decrease in symptomatic students, while remaining stable in asymptomatic students. Additionally, based on previous research<sup>26,27</sup>, we expected a more rigid or random temporal structure of CoP oscillations if postural control changes were mediated by pain or decreased proprioception, respectively.

	Control group ( $n=23$ )		Neck pain group ( $n=21$ )		$p$
	Mean $\pm$ SD	[Range]	Mean $\pm$ SD	[Range]	
Age (years)	21.8 $\pm$ 1.92	[20–29]	22.9 $\pm$ 2.10	[21–30]	0.082 <sup>a</sup>
Height (m)	1.72 $\pm$ 0.08	[1.58–1.88]	1.68 $\pm$ 0.10	[1.54–1.92]	0.180 <sup>a</sup>
Body mass (kg)	63.3 $\pm$ 10.65	[46–86]	63.5 $\pm$ 11.81	[47–88]	0.950 <sup>a</sup>
BMI (kg/m <sup>2</sup> )	21.2 $\pm$ 2.11	[17.6–24.6]	22.4 $\pm$ 3.82	[16.9–35.3]	0.212 <sup>a</sup>
Sex % (n)	Male 43.5% (10)		Male 19.1% (4)		0.082 <sup>b</sup>
	Female 56.5% (13)		Female 80.9% (17)		

**Table 1.** Sociodemographic characteristics of the participants. *BMI* Body mass index, *SD* standard deviation; <sup>a</sup>Student's t-test; <sup>b</sup>Chi-square test.

Stance	Position	Axis	Control			Neck Pain		
			Baseline Mean $\pm$ SD	Endpoint Mean $\pm$ SD	<i>p</i>	Baseline Mean $\pm$ SD	Endpoint Mean $\pm$ SD	<i>p</i>
Narrow	0° OE	AP	0.13 $\pm$ 0.05	0.12 $\pm$ 0.04	0.785 <sup>b</sup>	0.16 $\pm$ 0.08	0.15 $\pm$ 0.06	0.675 <sup>b</sup>
		ML	0.27 $\pm$ 0.06	0.19 $\pm$ 0.04	0.170 <sup>a</sup>	0.25 $\pm$ 0.07	0.20 $\pm$ 0.04	0.986 <sup>a</sup>
	0° CE	AP	0.15 $\pm$ 0.05	0.17 $\pm$ 0.05	0.372 <sup>a</sup>	0.18 $\pm$ 0.04	0.16 $\pm$ 0.04	0.260 <sup>a</sup>
		ML	0.27 $\pm$ 0.06	0.20 $\pm$ 0.05	0.460 <sup>b</sup>	0.25 $\pm$ 0.07	0.22 $\pm$ 0.07	0.849 <sup>b</sup>
	60° OE	AP	0.13 $\pm$ 0.05	0.14 $\pm$ 0.04	0.788 <sup>a</sup>	0.14 $\pm$ 0.05	0.15 $\pm$ 0.05	0.840 <sup>a</sup>
		ML	0.27 $\pm$ 0.06	0.17 $\pm$ 0.04	0.907 <sup>b</sup>	0.25 $\pm$ 0.07	0.18 $\pm$ 0.06	0.648 <sup>b</sup>
60° CE	AP	0.18 $\pm$ 0.06	0.16 $\pm$ 0.04	0.406 <sup>a</sup>	0.18 $\pm$ 0.04	0.16 $\pm$ 0.07	0.702 <sup>a</sup>	
	ML	0.27 $\pm$ 0.06	0.20 $\pm$ 0.06	0.228 <sup>b</sup>	0.25 $\pm$ 0.07	0.21 $\pm$ 0.06	0.270 <sup>b</sup>	
Tandem	0° OE	AP	0.23 $\pm$ 0.13	0.26 $\pm$ 0.09	0.013 <sup>b*</sup>	0.24 $\pm$ 0.12	0.17 $\pm$ 0.07	0.004 <sup>b*</sup>
		ML	0.27 $\pm$ 0.06	0.29 $\pm$ 0.08	0.015 <sup>a*</sup>	0.25 $\pm$ 0.07	0.25 $\pm$ 0.07	0.405 <sup>a</sup>
	0° CE	AP	0.28 $\pm$ 0.11	0.30 $\pm$ 0.15	0.697 <sup>b</sup>	0.32 $\pm$ 0.16	0.27 $\pm$ 0.13	0.341 <sup>b</sup>
		ML	0.27 $\pm$ 0.06	0.28 $\pm$ 0.07	0.585 <sup>a</sup>	0.25 $\pm$ 0.07	0.30 $\pm$ 0.10	0.351 <sup>a</sup>
	60° OE	AP	0.28 $\pm$ 0.13	0.27 $\pm$ 0.13	0.907 <sup>b</sup>	0.28 $\pm$ 0.13	0.22 $\pm$ 0.12	0.058 <sup>b</sup>
		ML	0.27 $\pm$ 0.06	0.27 $\pm$ 0.09	0.437 <sup>b</sup>	0.25 $\pm$ 0.07	0.26 $\pm$ 0.07	0.621 <sup>b</sup>
60° CE	AP	0.34 $\pm$ 0.10	0.33 $\pm$ 0.10	0.997 <sup>a</sup>	0.27 $\pm$ 0.12	0.35 $\pm$ 0.15	0.080 <sup>a</sup>	
	ML	0.27 $\pm$ 0.06	0.29 $\pm$ 0.06	0.123 <sup>a</sup>	0.25 $\pm$ 0.07	0.29 $\pm$ 0.10	0.120 <sup>a</sup>	

**Table 2.** Within group comparison over the first semester of clinical practice. 0° = cervical neutral position; 60° = 60 degrees of cervical left rotation; AP anterior–posterior, CE Closed eyes, OE Open eyes, *p* p-value, SD Standard deviation, ML medial-lateral; <sup>a</sup> Repeated Measures ANOVA; <sup>b</sup> Friedman test; \**p*-value < 0.05.

Stance	Position	Axis	Baseline			Endpoint		
			Control Mean $\pm$ SD	Neck Pain Mean $\pm$ SD	<i>p</i>	Control Mean $\pm$ SD	Neck Pain Mean $\pm$ SD	<i>p</i>
Narrow	0° OE	AP	0.13 $\pm$ 0.05	0.16 $\pm$ 0.08	0.456 <sup>b</sup>	0.12 $\pm$ 0.04	0.15 $\pm$ 0.06	0.231 <sup>b</sup>
		ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.316 <sup>a</sup>	0.19 $\pm$ 0.04	0.20 $\pm$ 0.04	0.787 <sup>a</sup>
	0° CE	AP	0.15 $\pm$ 0.05	0.18 $\pm$ 0.04	0.170 <sup>a</sup>	0.17 $\pm$ 0.05	0.16 $\pm$ 0.04	0.854 <sup>a</sup>
		ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.013 <sup>b*</sup>	0.20 $\pm$ 0.05	0.22 $\pm$ 0.07	0.173 <sup>b</sup>
	60° OE	AP	0.13 $\pm$ 0.05	0.14 $\pm$ 0.05	0.953 <sup>a</sup>	0.14 $\pm$ 0.04	0.15 $\pm$ 0.05	0.965 <sup>a</sup>
		ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.316 <sup>b</sup>	0.17 $\pm$ 0.04	0.18 $\pm$ 0.06	0.424 <sup>b</sup>
60° CE	AP	0.18 $\pm$ 0.06	0.18 $\pm$ 0.04	1.000 <sup>a</sup>	0.16 $\pm$ 0.04	0.16 $\pm$ 0.07	0.985 <sup>a</sup>	
	ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.401 <sup>b</sup>	0.20 $\pm$ 0.06	0.21 $\pm$ 0.06	0.397 <sup>b</sup>	
Tandem	0° OE	AP	0.23 $\pm$ 0.13	0.24 $\pm$ 0.12	0.470 <sup>b</sup>	0.26 $\pm$ 0.09	0.17 $\pm$ 0.07	0.002 <sup>b*</sup>
		ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.594 <sup>a</sup>	0.29 $\pm$ 0.08	0.25 $\pm$ 0.07	0.196 <sup>a</sup>
	0° CE	AP	0.28 $\pm$ 0.11	0.32 $\pm$ 0.16	0.514 <sup>b</sup>	0.30 $\pm$ 0.15	0.27 $\pm$ 0.13	0.466 <sup>b</sup>
		ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.824 <sup>a</sup>	0.28 $\pm$ 0.07	0.30 $\pm$ 0.10	0.713 <sup>a</sup>
	60° OE	AP	0.28 $\pm$ 0.13	0.28 $\pm$ 0.13	1.000 <sup>b</sup>	0.27 $\pm$ 0.13	0.22 $\pm$ 0.12	0.115 <sup>b</sup>
		ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.780 <sup>b</sup>	0.27 $\pm$ 0.09	0.26 $\pm$ 0.07	0.557 <sup>b</sup>
60° CE	AP	0.34 $\pm$ 0.10	0.27 $\pm$ 0.12	0.290 <sup>a</sup>	0.33 $\pm$ 0.10	0.35 $\pm$ 0.15	0.972 <sup>a</sup>	
	ML	0.27 $\pm$ 0.06	0.25 $\pm$ 0.07	0.912 <sup>a</sup>	0.29 $\pm$ 0.06	0.29 $\pm$ 0.10	0.996 <sup>a</sup>	

**Table 3.** Between group comparison over the first semester of clinical practice. 0° = cervical neutral position; 60° = 60 degrees of cervical left rotation; AP anterior–posterior, CE Closed eyes, OE Open eyes, *p* p-value, SD Standard deviation, ML medial-lateral, <sup>a</sup>Repeated measures ANOVA; <sup>b</sup>Mann–Whitney U test; \**p*-value < 0.05.

Our results revealed that the complexity of CoP oscillations changes over time as students begin their clinical practice. Notably, these changes differed between asymptomatic students and those with ongoing neck pain. Contrary to our hypothesis, the asymptomatic group exhibited a more random temporal structure over time, despite our expectation that their postural control would remain stable. We anticipated that healthy students would experience minimal and undetectable changes in their postural control.

In complex mechanical systems such as human postural control, transitions from a more regular to an irregular structure can be attributed to altered interferences from other processes, such as various interacting control or perturbation processes<sup>42</sup>. The adaptation to clinical practice could potentially disrupt the hierarchy within the postural control system and alter the time scales on which its sub-systems operate<sup>42</sup>. This is because high-level cortical involvement increases as postural challenges or demands for reactive control rise<sup>43</sup>. Reflex circuits influence postural movements with a typical delay of 20–50ms<sup>44</sup>, whereas higher cognitive functions

typically require more than 100ms to compute sensory information and initiate postural responses<sup>42</sup>. Adapting to new tasks and transitioning to a more cognitively demanding environment could temporarily impair the efficacy of proprioceptive function due to its delayed response, resulting in the more random temporal structure of CoP fluctuations observed in asymptomatic students. However, we would expect this to become detectable if we assessed the students in their working positions and not in an experimental setting. We do not expect the proprioception of these students to be impaired or changed outside the clinical setting tasks. One alternative explanation could be the demands of the tandem stance in the initial setting. Since this balance task was performed for the first time during the baseline assessment, participants might have adopted a more conscious postural control in unstable positions, leading to a baseline entropy for a healthy system, in this position, that is lower than expected. Despite the absence of differences in other positions in the control group, such as tandem stance with closed eyes, they also show higher entropy at the endpoint, which could support this explanation. To fully understand this variation, we would need continued assessment of these students to observe two possible paths in entropy variability. If, after the initial adaptation period, we observe a return to baseline complexity levels, it would indicate that the initial increase in randomness is part of the adaptation process, and over time, the postural control system recalibrates to restore optimal complexity and functionality. Conversely, if complexity levels remain unchanged compared to the study endpoint, it would suggest that the entropy level representing a healthy system is the level observed at the end of the first semester and onward.

In line with our hypothesis, we observed that students with neck pain exhibited a more rigid temporal structure in their CoP oscillations, particularly in the anterior-posterior direction which is aligned with previous findings<sup>10,33</sup>. The control of equilibrium and internal displacements of muscle fibers, ligaments, and soft tissues extends beyond distal joints. Postural stability necessitates constant activity of axial muscles to stabilize the trunk and head, compensating for movements of distal body parts as needed<sup>43</sup>. Postural control involves various neuromuscular components operating on different time scales, including mechanical processes, reflex loops, anticipatory or feed-forward processes, and exploratory behaviors orchestrated by the central nervous system to generate effective proprioceptive sensory information<sup>42</sup>. Previous evidence<sup>26,27</sup> suggests that the presence of pain can trigger protective mechanisms and fear-avoidance behaviors. Although the exact neural mechanisms remain unclear, postural threat can elicit modifications to standing balance. Shifts in attention, such as directing more focus to balance when threatened, may contribute to these changes. Sample entropy, a measure of postural sway regularity, indicates that lower values reflect less automatic and more conscious control of balance. This supports the notion that increased attention to balance can explain threat-induced changes<sup>45</sup>. Shifting postural control from an automatic process to a more conscious one can negatively impact CoP oscillations complexity, leading to a more rigid and less adaptable system. This irregularity in the CoP patterns can also result in an undesirable loading of some anatomical structures in the cervicothoracic region.

Conversely, upright bipedal stance relies on vision, vestibular, and somatosensory input to maintain postural equilibrium and proper alignment of body segments with respect to gravity<sup>43</sup>. Thus, the traditional notion of postural reflexes could be insufficient to account for the full complexity of postural control. Instead, postural control encompasses anticipatory or feedforward adjustments, context-dependent sensorimotor or reflex modulations, the postural body scheme, and the integration of posture and movements<sup>43</sup>. This broader perspective may explain why the observed changes in CoP complexity were not consistent across different assessment conditions, including variations in visual feedback, cervical rotation, and stance width. As previously described, the AP direction seemed more sensitive to detect balance deficits related to neck pain<sup>10,33</sup>. An analysis of the control group's SampEn values reveals that the inclusion and combination of perturbations increased postural control entropy. We hypothesized that the differences in postural control complexity between the control and experimental groups during tandem stance would increase with additional perturbations, such as the removal of visual feedback and a heightened reliance on proprioceptive and vestibular systems. Previous research indicates that increased postural sway is an exploratory strategy employed by the central nervous system to acquire essential sensory information from the environment, particularly when information from other sensory systems is absent or reduced<sup>33</sup>, but, other stated that the augmentation of visual information regarding the motion of the CoP alone has failed to enhance balance performance and may even increase postural sway<sup>46</sup>. However, excessive perturbations appear to hinder the accurate assessment of postural control complexity in these students, contradicting previous research that reported no significant differences in sway parameters in different positions<sup>47</sup>. It is expected that stances with fewer perturbations may not sufficiently highlight postural control differences due to their stability. Therefore, tandem stance with visual feedback and a neutral cervical position seems suitable for detecting changes in postural control complexity in these students. This conclusion should be approached with caution since, according to the nonlinear dynamics theoretical framework, postural control emerges from the interaction of individual physiological systems, task demands, and environmental constraints. Nonlinear systems self-organize based on initial conditions and simple rules governing interactions among basic components. Since these components form multi-link networks, simple interactions do not predict the system's overall behavior, especially over longer time scales. Depending on initial conditions, small perturbations can have no effect, a proportional effect, or a dramatic effect on system output<sup>15</sup>. Unlike linear models, which analyze the magnitude of output signal variability and focus on individual system components, nonlinear models use the time-evolution properties of an output signal to infer interactions within the underlying control system. Nonlinear dynamics, such as entropy measures of postural control, reflect the central nervous system's functioning and its ability to adapt and remain flexible in an unpredictable and ever-changing environment<sup>15</sup>.

While our study assessed postural control exclusively in upright stance, it's important to consider the practical implications for dental students who are taught to alternate positions and perform part of their clinical tasks in a seated posture to reduce fatigue and musculoskeletal symptoms by shifting muscular support between opposing muscle groups<sup>29-31</sup>. Despite the similar neck symptoms between dentists who work in sitting positions and

those who alternate between sitting and standing<sup>29,30</sup>, we know that the seated postures may result in higher muscular loads on the neck, shoulder, and back muscles compared to standing postures<sup>32</sup>. Therefore, the path towards a more conscious and rigid postural control in students with neck pain in standing position might reflect or contribute to inefficiencies in maintaining stability and ergonomically favorable positions when seated, potentially exacerbating the higher musculoskeletal strain observed in this work position<sup>32</sup>, hindering the benefit of altering work positions described in current literature<sup>29–31</sup>.

Our results indicate that neck musculoskeletal symptoms in dental students may impair their postural control, potentially affecting their ability to perform clinical training effectively and eventually contributing to the recurrence and chronicity of these symptoms. These findings highlight the need for increased involvement from educators, clinicians, and researchers to support further investigation on this issue. A deeper understanding of postural control complexity in dental students is essential for developing preventive and intervention measures aimed at restoring the postural complexity to its optimal level.

While our study was designed to overcome the weaknesses of previous research, such as having a longitudinal design instead of a cross-sectional<sup>33</sup>, it still faced some limitations. We used a single repetition for each position, and despite assuring proper execution, the individual performance in a single repetition could influence the obtained results. Postural control assessments were made only in standing position, which limit the depth of our analysis regarding the sitting work posture. The presence of confounding factors associated with pain such as kinesiophobia were not addressed and could impact the results. Other limitation of our study is the unbalanced sex distribution in the neck pain group, which, despite reflecting the lower percentage of male students in the studied population, might have affected the outcomes. Finally, despite the restricted criteria for participants, we cannot fully exclude the influence of confounding variables such as impaired proprioception in any level below the cervical region did not affect the results.

Future research could explore the continued dynamics of postural control in this population over a broader period to enhance knowledge of its variability in these students. The inclusion of assessments in seated positions could provide a more comprehensive understanding of how neck pain influences dental students' ability to maintain optimal working postures during treatments. Future studies that involve data collection during clinical practice and not in an experimental setting could enhance our understanding of postural control complexity in these students. Additionally, investigating the influence of preventive or rehabilitation programs on restoring postural control complexity and understanding the dynamics of postural control after the application of such programs could provide further insights into their effectiveness.

## Conclusion

The present study showed that dental students' postural control complexity decreased during the first semester of clinical practice. The center of pressure oscillations became more irregular in asymptomatic students and more rigid in students with neck pain. The asymptomatic group path to a random temporal structure over time indicates a possible motor control adaptation to a new task. In contrast, the decrease in postural control complexity in students with neck pain could indicate a less automatic and more conscious control of balance. Future research should explore long-term changes in postural control variability during clinical training and the development of prevention and intervention programs to address this decrease in complexity.

## Data availability

The dataset used during the current study is published in open access on Mendeley Data and available from <https://data.mendeley.com/datasets/mn944d3tdw/1>.

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### Author contributions

Conceptualization, M.A., M.M., J.M., J.V., P.M. and R.O.; Data curation, M.A., M.M., J.M. and J.V.; Formal analysis, M.A., J.M., J.V., P.M. and R.O.; Funding acquisition, M.A. and R.O.; Investigation, M.A. and M.M.; Methodology, M.A., M.M., J.M., J.V., P.M. and R.O.; Project administration, M.A.; Resources, M.A., J.V., and R.O.; Software, M.A. and J.V.; Supervision, P.M. and R.O.; Validation, J.V., P.M. and R.O.; Writing—original draft, M.A.; Writing – review & editing, M.A., M.M., J.M., J.V., P.M. and R.O.

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### Declarations

#### Competing interests

The authors declare no competing interests.

#### Ethical statement

Informed consent was obtained from all participants.

#### Additional information

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