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Exploring postural risk reduction in dental training: an observational study using motion and haptic sensors

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Abstract

Background and objectives: Current dental curricula lack a defined system for ergonomic training or competence assessment, essential for preventing musculoskeletal disorders (MSDs). Motion analysis offers significant potential in evaluating dental operator posture and the impact of interventions as part of a risk reduction strategy. This observational study aimed to assess the practical application of ergonomic training after preclinical preparation in dental students, and the effectiveness of haptic feedback in correcting high-risk postures. Additionally, it compared a commercial OHS ergonomic analysis software with visual posture assessment to evaluate inclusion for feedback potential as part of training in the curriculum.

Methods: Twenty second-year dental students at The University of Queensland were selected randomly. Students performed scaling tasks in a standard operatory, with postures tracked by motion sensors. Haptic sensors provided feedback on high-risk postures, while visual posture assessments through video analysis were compared with commercial OHS software data.

Results: The practical application of prior ergonomic training despite theoretical revision was poor and inconsistent. Response to haptic warnings was positively demonstrated by all participants, yet only 20% maintained corrected posture throughout the task. The OHS software provided a detailed comprehensive examination of body segments at risk and intervention impacts at a higher level of detail compared to current observer-based ratings methods.

Conclusions: The study highlights the gap in practical testing and theoretical ergonomic training among dental students. Earlier postural habit development and testing should be considered before introduction of demanding high-level dental tasks. Standardized systems using sensors or video analysis could provide real-time feedback to aid detection of high-risk posture.

Introduction

Musculoskeletal disorders (MSDs) pose a significant health concern for dental professionals, with an estimated prevalence at 78% (Lietz *et al.*, 2020). These disorders result from prolonged static postures during dental procedures. MSDs cause persistent pain and can lead to early retirement or reduced clinical time for up to third of the dental workforce (Burke *et al.*, 1997). While much research has focused on the prevalence of MSDs (Ohlendorf, 2020; Sakzewski and Naser-ud-Din, 2014; Moodley, 2018; Yamalik, 2006; Rucker and Sunnell, 2003; Anghel, 2007; Blume, 2021), risk factors (Yamalik, 2006; Rucker and Sunnell, 2003; Anghel, 2007; Blume, 2021), and interventions (Mulimani, 2018; Roll, 2019; Lietz, 2020; Dehghan, 2016), less emphasis has been placed on intercepting and correcting poor postural habits during training.

Up to 90% of graduate dental students have been identified with some form of MSD from their undergraduate preclinical and clinical training, which suggests that ergonomic training is insufficient, and students fail to apply in practice the knowledge gained from theoretical lectures on ergonomics (Hayes *et al.*, 2009). A possible cause could be insufficient testing and reinforcement of ergonomics during dental education. A Test of Visual Perception (TVP) from photographs (Garbin, 2011), found that final-year dental students demonstrated high recognition of postural requirements, however their practical application was inadequate. Similarly, through a self-assessment questionnaire identified that students' theoretical knowledge of ergonomic posture exceeded their practical application (Garcia *et al.*, 2015). A further study found that 96% of third year and higher dental students understood the theory of proper posture and its health implications, yet only 28% adhered to ergonomic standards in practice (Cerver-Espert *et al.*, 2018). These results emphasise not only the need for better integration of practical ergonomic training in dental curricula but evaluation and measurement of training to bridge the gap between knowledge and application.

Global research and guidelines on postural risk reduction in dental curricula are still limited. An evaluation done across 216 accredited US dental hygiene programs found basic ergonomic training (e.g., patient positioning) was common but additional education (beyond patient/operator positioning and instrumentation: for example, body mechanics or preventive exercises) was generally unavailable or available only on a limited basis to dental hygiene students even though most hygiene programs reported that students were experiencing MSD symptoms (Beach and DeBiase, 1998.)

A major challenge in posture studies is finding a tool that is valid, reliable, and easy to use for assessing range, duration, and frequency of postural risk during an entire clinical task performance and tracking the effectiveness of any proposed interventions. Ideally, such a tool should continuously monitor posture without disrupting clinical procedures and provide real-time feedback when high-risk postures occur. It should also assess how students respond to interventions aimed at correcting poor posture. Historically, visual rating tools have been the primary method for assessing posture) The Posture Assessment Instrument (PAI; Branson *et al.*, 2002) the first such tool used in dentistry was an adaptation of the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) tools (McAtamney and Corlett, 1993). Various other tools have been developed-the Competence Assessment of Dental Ergonomic Posture (CADEP; Garcia *et al.*, 2018)). the Test of Visual Perception (TVP; Garbin *et al.*, (2011), the Dental Ergonomic Assessment (DEA; Kamal *et al.*, 2020), the Posture Assessment Criteria (PAC; Maillet *et al.*, 2008) and the Standard Photometric Assessment method (SPAM; Muthuraj *et al.*, 2020) and the Modified Operator Posture Assessment Instrument (MOPAI; Partido, 2017; Partido and Wright, 2018; Partido, 2020; Partido and Hendeson, 2021) using photography as an self-assessment tool have been introduced to evaluate specific posture components. However, these are often complex, and costly in terms of time and rater training and lacked continuous real-time feedback.

More recently, motion sensor systems have emerged as alternatives. Marker-less motion sensor analysis, widely used in sports and rehabilitation, has had limited application in dentistry, though more complex camera setups restrict its use to pure research. A digital Ergonomic Trainer System (ETS; Thanathornwong and Suebnukarn, 2020) incorporated ultrasonic sensors and accelerometers for feedback for posture evaluation. The XSens Bluetooth-based Motion Virtual Network (MVN) Link system (Enschede, Netherlands), commonly used in sports science and motion capture, has shown potential in dentistry. Several studies have used the Xsens system (Holzgreve, 2022; Blume, 2021; Ohlendorf, 2021; Maurer-Graubinger, 2021) and demonstrated promising outcomes in broadening the validation of ergonomic tools such as RULA, comparing postures across dental disciplines, and optimising workspace designs postural performance across dental disciplines. Post-event statistical analysis is commonly done using MATLAB (The MathWorks Inc. Natick MA, USA).

Given the importance of ergonomics in preventing MSDs, the present study examined the effectiveness of prior ergonomic training in dental students, to attempt to quantify disconnects between their theoretical knowledge and practical application. This study also explored the potential benefits of haptic feedback technology in reinforcing proper postural habits, which would reduce MSD risk in future dental professionals. From these broad aims the study developed three primary objectives: first, to evaluate how well students applied their ergonomic training after preclinical operative training; second, to assess whether haptic vibration feedback could prompt posture correction and maintain safer ergonomic positions; and third, to pilot the use of a commercially available evaluation tool called Industrial Athlete software by Scalefit (Köln, Germany), which uses XSens data to evaluate if a deeper level of postural risk analysis could be achieved than current methods of visual rating systems. Ultimately, the goal was to bridge the gap between theoretical knowledge and practical application and improve ergonomic practices to reduce MSD risks in the dental field, as shown in flow diagram.

Materials and methods

The study was approved by the Human Ethics Committee of the University of Queensland (UQ), Approval No. 2022/HE000057. This study focused on second-year students before they started clinical work. The ranking and application of ergonomic principles was determined by assessing seven key postural elements known to be critical in both dental and industrial occupational health and safety (OHS) studies: 1. Initial starting dentist/patient positioning; 2. Head/neck position; 3. Body torso position; 4. Arm and shoulder positions; 5. Sitting upper/lower leg angle; 6. Feet flat on the floor and rheostat positioning; and 7. Visual working distance.

Study participants: All year 2 dental students were invited to participate, and 20 students of varying heights and weights volunteered to participate. The study process is described in Figure 1. Their posture was evaluated during their first practice session while conducting a basic scaling and cleaning task, with a follow-up observation and evaluation conducted six weeks later. The clinical task was performed using a standard side-delivery dental operatory chair (A-dec 400, ADEC Solutions Inc., Newburgh, OR, USA), paired with a traditional 5-wheel

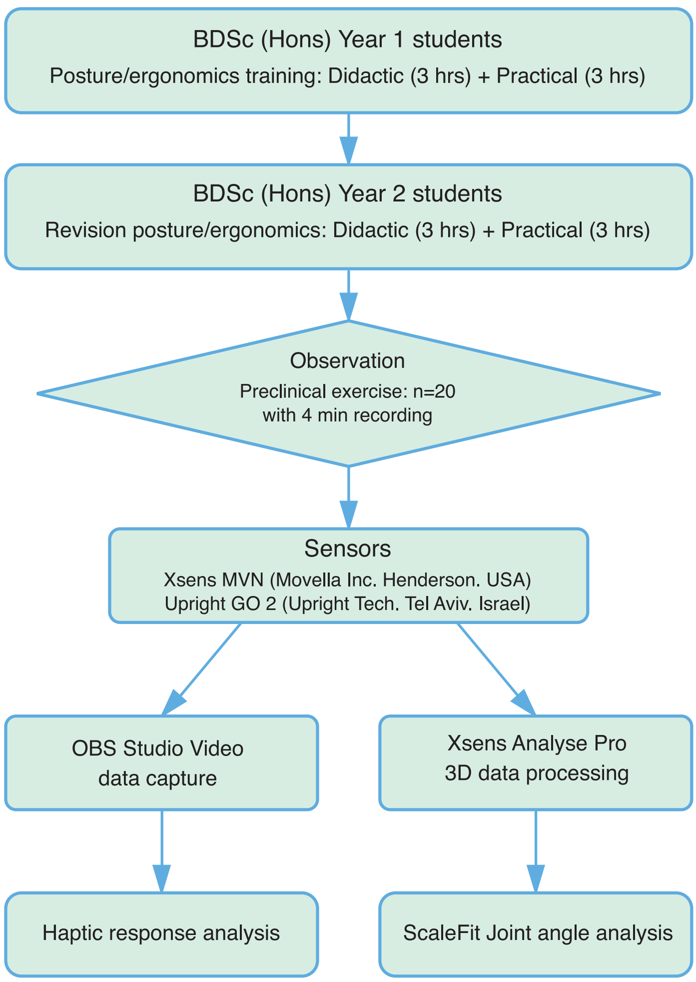

Figure 1. Flow diagram of the study.

operator stool with adjustable height, back support, and pan tilt. Chair-mounted overhead lighting was provided for the task. Magnification loupes were not used. All participants reported being healthy, and free of any physical impairments. Data collection*:* Within the current curriculum students attend a 3-hour lecture on ergonomics and complete 3-hours of practical application of this content in clinic during their first year. Prior to commencing the study students participated in a group review of ergonomic principles. via a 2-hr lecture and a 3-hr practical hands-on practical session provided by the principal author.

Before the study, participants were given an information sheet explaining the technical aspects of the study, and all provided signed consent to participate. No practical session was offered in advance to allow participants to familiarise themselves with the technologies used in the study as an element to try to prevent performance bias. Students were divided into groups of three – one as the participating operator, one acting as the dental assistant, and the third acting as the patient.

Posture tracking and measuring was carried out using two systems. The first system employed XSens MVN motion sensors (Awinda, Movella Inc, Henderson, NV, USA) The system uses seventeen Velcro-retained, three-axis accelerometer sensors connected wirelessly via Bluetooth, to capture the movement of seventeen body segments generating areal time avatar equivalent. The data collected was then processed using proprietary XSens Analyze Pro software for full body kinematic posture and joint analysis. The sampling rate was 240 Hz. The measurement error was specified by the manufacturer as ± 1%.

Concurrently, a secondary single wearable haptic sensor with two internal directional movement sensors (Upright Go 2.0, Upright Technologies Ltd, Tel Aviv, Israel) was used. This provided real-time feedback of head/neck postural risk through a smartphone app. The app displayed an onscreen avatar, which visually mirrored the actual body position. The avatar changed colour from green to red when posture deviated from the designated safe limit, and the device vibrated gently if the posture deviation was sustained beyond a preset threshold.

Simultaneous recording of display outputs from both systems was performed using open-source video recording software for real-time video and audio capture (Open Broadcaster Software v30.1.0, and OBS Studio, Lain Bailey). Video recordings of side and rear views of participants were made via two iPhone 10 (Apple Inc) cameras positioned one-meter away and at one metre above floor level in height. Participants wore both motion sensor systems with the haptic sensor attached via Velcro adhesive to the headband holding one of the XSens sensors (Figure 2).

Participants received instruction that during the task, the haptic sensor would vibrate if their head or neck posture exceeded 20 degrees of forward flexion for more than five seconds and the haptic sensor was calibrated directly through the app. Calibration for the MVN Awinda motion sensors took 20 seconds in a standardised neutral (N) position Participants were not told when recording would start to aid reduction of any performance bias. After a two-minute normalisation period, video and motion

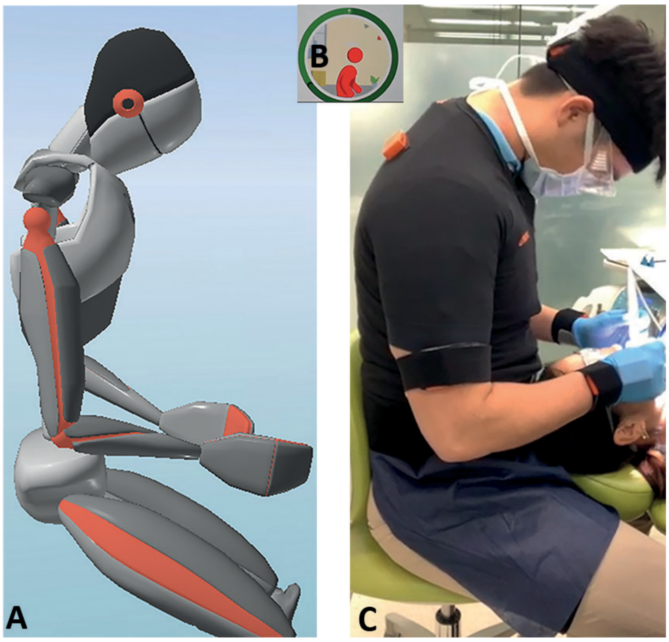

Figure 2. Posture and Haptic Recording. **A**. Xsens digital avatar recorded representation of student's posture**. B**. Posture2Go digital displaying matched RED high-risk posture. **C**. Student wearing orange Xsens sensors together with UPRIGHT GO 2™ applied to headband posteriorly.

sensor recordings were conducted for four minutes to evaluate body segments. This was followed by another four minutes of haptic sensor application to gather pre- and post-intervention data.

Evaluation of postural performance: A scoring tool was developed by synthesising the validated Posture Assessment Instrument (PAI; Branson, 2002) the Posture Assessment Criteria (PAC; Maillet *et al.*, 2008) and the Modified Operator Posture Assessment Instrument (M-DOPAI; Partido, 2017; Table 1). The tool had seven elements, with three levels of grading, as given below:

1. Initial starting dentist/patient positioning: good/fair/poor
2. Head/neck position: good/fair/poor
3. Body torso position: good/fair/poor
4. Arms and shoulder position: good/fair/poor
5. Sitting upper/lower leg angle between 100-125 degrees: good/fair/poor
6. Feet flat on the floor and rheostat positioning: good/fair/poor
7. Visual working distance: good/fair/poor

Data analysis: To reduce subjective variability between raters, the postural scoring ranges from "Acceptable (Good)" "Compromised (Fair)," and "Harmful (Poor)" were divided further into two levels (Table 2). Two independent, non-staff visual raters reviewed video recordings of all participants and scored their posture. Inter and intra rating training and standardisation previously developed through several studies (Partido, 2017; Partido and Wright, 2018; Partido, 2020; Partido and Henderson, 2021) were applied. Scoring was based on six levels: Acceptable-Good (6 points), Fair-Good (5 points), Compromised-Fair (4 points), Fair-Poor (3 points), Compromised-Poor (2 points), and

Table 1. Scoring Evaluation using visual rating adapted from Maillet (PAC) (2008) and Branson PAI (2002) and Partido M-DOPAI (2017).

Acceptable (0 points)	Compromised (1 point)	Harmful (2 points)
Hip and Legs		
Hips level on stool: Upper thigh parallel; feet flat on floor	Hips NOT level on stool: upper thighs NOT parallel; feet NOT on floor	
Trunk		
Front to back≤20° Side to side ≤20°	Front to Back ≤20° to ≤45° Side to side ≤20° to ≤45°	Front to back ≥45° Side to side ≥45°
Head and Neck		
Front to back≤20° Side to side ≤20°	Front to Back ≤20° to ≤45° Side to side ≤20° to ≤45°	Front to back ≥45° Side to side ≥45°
Upper Arms		
Upper arms parallel to long axis of torso Elbows at waist level	≤20° of elbow abduction away from the torso Elbows ≤ 30° above horizontal	≥ 20° of elbow abduction away from torso Elbows ≥ 30° above horizontal
Shoulders		
Relaxed Both shoulders level	Slumped forward Both shoulders elevated above trunk	

Table 2. Evaluation of Postural Performance.

Dominant Hand	Height of Operator	1	2	3	4	5	6	7	
Left (L); Right (R)	Tall(T); Medium (M); Short (S)	Dentist/ Patient Position	Neck position: good/fair/poor	Body/torso position: good / fair/poor	Arms/shoulders position: good/fair/poor	Legs -110-125° high/knee angle+ lower leg perp. to floor: good/fair/poor	Feet position– flat on floor: good/fair/poor	Working Distance: estimate	Score%
L	M	3	2	2	4	4	4	3	22
R	M	5	2	3	4	4	4	3	25
R	M	5	4	2	4	4	4	4	27
R	T	5	4	5	5	5	2	6	32
R	T	2	2	2	3	5	5	6	25
L	M	5	5	5	4	5	4	6	34
R	T	1	2	2	2	2	2	4	15
L	M	1	1	2	2	5	5	5	21
R	T	2	2	1	2	2	2	4	15
R	M	6	1	5	5	6	4	3	30
R	S	2	1	2	2	4	4	2	17
R	S	2	2	2	2	2	2	1	13
L	M	5	6	6	6	5	5	4	37
R	M	5	4	3	5	5	5	4	31
R	M	6	1	6	6	6	5	4	34
R	M	4	2	4	4	6	5	4	29
R	M	4	4	5	4	3	5	4	29
R	T	4	2	4	4	5	4	3	26
	SCALE	Poor-Severe	Poor	Fair to Poor	Fair	Fair to Good	Good		
		1	2	3	4	5	6		

Scoring Criteria: 1.the dentist/patient starting position- symmetrical/non symmetrical/at 9 o'clock position during recording pre and post haptic stimulus; 2. Head/neck angle of forward flexion during recording pre and post haptic stimulus; 3. Body/torso angle of flexion/ rotation/leaning during recording pre and post haptic stimulus; 4.Arms/shoulders- elevation/abduction/rotation during recording pre and post haptic stimulus; 5. Upper leg/lower leg angle and variation to perpendicular to floor during recording pre and post haptic stimulus; 6. Feet/flat on floor/equally balanced during recording pre and post haptic stimulus; 7.Visual working distance during recording pre and post haptic stimulus.

Poor-Severe (1 point). A traffic light colour grading system (red, yellow and green) was used to visually represent the six response levels.

A separate experiment for testing and analysis of digital data for one male and female participant was performed using commercial software (Industrial Athlete, ScaleFit UG, Cologne, Germany) to compare and evaluate the outputs in terms of benefits and potential to impact postural behaviour. Following data acquisition via the Awinda sensors, the data was then processed via Xsens Analyse Pro, with further high-level analysis by Industrial Athlete in terms of body segment postural risk, range of motion, duration, frequency of body segment angles and vertebral disc compression.

Results

Of the 20 participants, six were male and 14 were female. However, two participants were excluded as some of their digital data was not collected fully.

Table 3. Scalefit results showing frequency, number and maximum and time weighting and daily dose.

Database (Frequency, number and maximum)					
Physical Stress	**No.**	**No/min**	**No.**	**No/Min**	**Max**
Trunk Inclination	52	5.6	0	0.0	10°
Lumbar disc compression			0	0.0	1.6kN
Load			0	0.0	0 kg
Head Torsion			1	0	29°
Head Inclination	84	8.7	35	3.6	54°
Cervical disc compression			41	4.3	250 N
Arm Elevation Left	56	5.8	5	0.5	101°
Arm Elevation Right	42	4.4	2	0.2	104°
Shoulder moment left (STA)			0	0.0	9 Nm
Shoulder moment right (STA)			0	0.0	2 Nm
Above shoulder work left			2	0.2	32 cm
Above shoulder right			3	0.3	41cm
Velocity			0	0.0	2 km/h
Wrist flexion/extension left			0	0.0	-46°
Wrist extension right			0	0.0	32°
Wrist abduction left			26	2.7	-44°
Wrist abduction right			23	2.4	-29°

Database (Time -weighting and daily dose)							
Physical Stress	**Low (75%)**		**Medium (25%)**		**High (10%)**		**RISK Level (%)**
	Time %	**Dose/day (h:mm:ss)**	**Time %**	**Dose/day (h:mm:ss)**	**Time %**	**Dose/day (h:mm:ss)**	
Trunk Inclination	24	00:02:16	76	00:07:10	0	00:00:00	Medium
Lumbar disc compression	100	00:09:37	0	00:00:00	0	00:00:00	Low
Load	100	00:09:37	0	00:00”00	0	00:00:00	Low
Head Torsion	100	00:00:36	0	00:00:00	0	00:00:00	Low
Head Inclination	9	00:00:50	12	00:01:06	80	00:07:41	High
Cervical disc compression	21	00:02:02	11	00:07:56	48	00:04:38	High
Arm Elevation Left	46	00:04:26	52	00:05:02	1	00:00:00	Medium
Arm Elevation Right	50	00:04:46	50	00:04:46	1	00:00:00	Medium
Shoulder moment left	8	00:09:23	2	00:00:13	0	00:00:00	Low
Shoulder moment right	99	00:09:32	1	00:00:05	0	00:00:00	Low
Above shoulder work left	98	00:09:27	0	00:00:02	1	00:00:07	Low
Above shoulder work right	99	00:09:28	0	00:00:02	1	00:00:06	Low
Velocity	100	00:09:37	0	00:00:00	0	00:00:00	Low
Wrist flexion/extension left	74	00:07:09	26	00:02:28	0	00:00:00	Medium
Wrist extension right	83	00:07:58	17	00:01:38	0	00:00:00	Low
Wrist abduction left	53	00:05:05	28	00:02:40	19	00:01:51	High
Wrist abduction right	52	00:04:59	43	00:04:09	5	00:00:29	Medium

Evaluation of postural performance

Only 10% of participants correctly assumed an optimal, symmetrical starting position relative to the patient chair (rating score greater and equal to 5). Although most had a reasonable understanding of the starting parameters, their ability to maintain a low-risk posture quickly diminished as task demands increased. Regarding head and neck position, over 90% of participants demonstrated postures ranging from fair to severe risk.(Rating score of four and less) Similarly, 70% showed fair to severe risk in maintaining a symmetrical upper body, with twisting and rotation commonly observed. In terms of forward and side arm raising, 75% of participants exhibited fair to severe risk in arm positioning. Furthermore, 50% demonstrated fair to severe risk while sitting, often due to the chair height being too high, causing their legs to be unsupported. Foot position and rheostat use also posed challenges, with 65% of participants failing to maintain heel contact on the rheostat, instead using only their toes. Finally, 80% of participants were classified as fair to severe risk for improper working distance from the patient. (Table 2).

Haptic response to identified postural risk

Response to the Upright Go 2.0 haptic stimulus: All participants responded positively to a haptic warning that their posture was incorrect. However, only 20% of participants made a postural correction in response to vibration and maintained that improved posture for the duration of the recording. The remainder demonstrated response to haptic feedback acknowledging a postural error was present but were unable to identify what specific component was responsible and could not correct the problem effectively. As the task demands increased, most participants quickly reverted to high-risk positions. Of the seven postural elements measured only the second postural performance element, involving head/neck adjustments and minor upper body corrections, showed some level of response. Postural elements 1, 4, 5, 6, and 7 showed no significant change in response to the haptic stimulus (Table 2).

The second component of this study assessing The ScaleFit Industrial Athlete software and their analysis report provided detailed monitoring of the response to the haptic reminder, showing its specific impact on body segments throughout the recording period, starting at the 240-second mark. After the haptic warning, there was a measurable reduction of high-risk head and neck angles and subsequent vertebral disc compression. Most notably, this software analysis allowed granular tracking of when participants responded to the haptic feedback, when its effect began to diminish, and when they eventually returned to higher-risk positions in each body segment (Table 3). The ScaleFit Industrial Athlete software also provided a comprehensive analysis of postural risk by reporting low, medium, and high-risk exposure times and angles, as well as cervical and lumbar disc compression risks caused by excessive head and neck flexion. It also measured wrist abduction and flexion, which is particularly important given the high incidence of carpal tunnel syndrome in the dental profession—an area not directly measured in any previous studies. In one sample case, the software identified high-risk neck flexion, cervical disc compression, and left wrist abduction (Table 3).

Discussion

Originally conceived as a pilot study-to evaluate the impact of haptic feedback to modify postural risk this study failed to meet the definition criteria of Lancaster *et al.,* (2004), where "pilot studies are used specifically to plan a randomised control trial (RCT)". Arain *et al.,* (2010) apply a broader definition of what is a pilot or feasibility study-citing Arnold *et al.*, (2009), where the observational design used in this study could be considered fitting their definition more of a "pilot work" – background research to inform a future study and fitting more broadly within the scope of their definition that a pilot study is "a small study for helping design a further confirmatory study". The small sample size weighted this study into concluding of being more of an observational study to inform future pilot study design.

The first element of this study was to examine the application by students of prior postural training and knowledge into their first clinical practice exposure. The results were consistent with previous studies that identified the difficulty translating knowledge of ergonomics to practical application, including Cervera-Espert *et al.,* (2002), Garcia *et al.*, (2018), Garbin *et al.*, (2011), Kamal *et al.*, (2020) and Muthuraj *et al.*, (2020). The high postural risk from forward head positioning and the other postural elements investigated in this study is consistent with past studies by Holzgreve *et al.*, (2022), Blume *et al.*, (2021), Ohlendorf *et al.*, (2021) and Maurer-Grubinger *et al.*, (2021), all of which used the Xsens sensor system to measure body angle segments. In those studies, dentists sat at the 9-10 o'clock position, and dental assistants at 2-3 o'clock.

Participants demonstrated a fair to poor understanding of the correct starting positions for both the operator and the patient. Participants failed to demonstrate any type of pre-set checklist of parameters, such as adjusting the patient chair or headrest based on the patient's size or the quadrant for the task Participants twisted, bent, or rotated their own bodies to adapt to the working field, rather than making necessary adjustments Few could find the optimal chair height position relative to their own height, leaving their lower body unsupported. No participant demonstrated resetting their feet, torso, or arms at distinct positions during the task, often resuming work in a high-risk posture. Taller and shorter operators had greater postural risks due to the limitations of the dental stools.

Consistent with previous studies evaluating prevalence and risk factors for MSD, the majority of participants sat with their heads less than 30 cm from the patient, a suboptimal visual working distance leading to head/neck strain. Their arm and shoulder positions showed high forward flexion, with lifted elbows often compensating for lateral leaning. The 9-10 o'clock and 2-3 o'clock operator positions were the most risk-prone, with head tilting and twisting compensating for the lack of visual symmetry. The relationship between the operator's foot and the speed control foot rheostat remains underexplored, but this study observed that universal postural imbalance occurred due to asymmetrical pivoting on one hip to operate the rheostat. This area needs further investigation.

The second element of this study examined the response to haptic reminders aimed at correcting at-risk postural performance. The results suggest a fair to low potential for providing actionable real-time feedback during task performance. The strength of this conclusion must consider the limited size and diversity of the cohort. In this regard, a limitation of the current study was its capacity to explore the influence of age, height, body mass index or weight on behaviour. Moreover, all participants were healthy. There is some suggestion in the literature height and weight could have a weak influence on the risk of MSD for dental assistants (Ohlendorf *et al.*, 2020), but these factors have not been explored for dental clinicians (Lietz *et al.*, 2018), for whom other variable such as gender, age, years of practice, and lack of stress reduction techniques seem more important. Yamalik (2006).

While the haptic stimulus was effective for signalling poor posture, this alert overwhelmed participants during tasks, making it challenging for them to maintain proper posture. Participants who started with poor posture showed little improvement in response to haptic feedback. This challenge of processing feedback during task performance aligns with findings from Thanathornwong and Suebnukarn (2020). In their study, audible feedback alerted participants to suboptimal posture but caused confusion regarding which body segment required correction For assessing posture, visual rating systems struggle to capture subtle, continuous changes in posture. Motion sensor technologies such as Xsens are preferred for gathering accurate postural data for evaluation and interpretation into existing risk assessment tools such as RULA and REBA, once these have been modified to suit the dental context (McAtamney and Corlett 1993; Blume *et al.*, 2021; Maurer-Grubinger *et al.*, 2021). The effectiveness of evaluating an interventions' capacity to generate a sustained lower risk posture via combining digital measurement with pre-existing visual risk rating systems needs further investigation.

This then leads to the third component of the study, which was an exploration and evaluation of commercial OHS software, Industrial Athlete by ScaleFit Systems. While this has been used in industrial OHS settings such as manufacturing industries, its use in dentistry is novel. This approach allowed more sophisticated analysis of continuous, real-time measurements from multiple body segments. Rather than giving an overall "risk score", this approach leads to scoring individual body segments according to time weighted exposure against a limit of daily dosage and frequency. This type of software could prove valuable for ergonomic training and for giving customised advice around reducing MSD risks, especially in tasks requiring prolonged static postures. Further studies using this approach to tracking body segment movements is warranted.

Strengths and limitations of this study were considerable. The increasing number of studies generating higher fidelity data by using a motion sensor system such as Xsens together with extensive body segment analysis using Scalefit software continues to show promise and potential application in the highly neglected area of occupational safety from developing MSD by all the dental workforce. However, there were many limitations that constrain the ability to draw anything but general conclusions-very limited sample size, testing during only one type of dental activity, the lack of control of the haptic sensor to possibly be applied to specific body segments and provide targeted feedback versus a universal warning. Numerous confounders exist within this and many other similar studies- the lack of identifying the depth of existing undergraduate training, testing and measuring their occupational risk to developing MSD; the lack of identifying accurately what type of dental stool and its optimum usage in study design; the range of different types of dental loupes, when introduced and how effective is their use and application confounds comparing different dental schools and to identify consistent major trends. These are just some strengths and limitations that future research needs to consider.

Conclusions

This study shows a gap between theoretical training in ergonomics and its practical application among dental students. This reinforces the need to develop, evaluate and test proper postural habits early, before students face the demands of complex dental tasks. The findings also underscore the need for a standardised tool to detect high-risk postures, provide real-time feedback for posture correction, and track the effectiveness of interventions. The study demonstrated the potential application of commercially available motion sensor technology and software in clinical training.

Author contributions

Conception or design of the work – SD, SZ, LW
Data collection – SD
Data analysis and interpretation – SD, LZ
Drafting the article – SD, AS
Critical revision of the article – all authors
Final approval of the version to be published – all authors

Conflict of interest

The authors declare no conflicts of interest.

Data statement

Participants were assured that the raw data of photographic images and survey responses would remain confidential and would not be shared without their written consent, in accordance with Australian Privacy Act provisions. Aggregated statistical data is available by contacting the corresponding author of this article.

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