International Journal of Occupational Safety and Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

A System for Predicting Musculoskeletal Disorders Among Dental Students

Bhornsawan Thanathornwong[a], Siriwan Suebnukarn[b] & Kan Ouivirach[c]
[a] Faculty of Dentistry, Srinakarinwirot University, Bangkok, Thailand
[b] Faculty of Dentistry, Thammasat University, Pathumthani, Thailand
[c] School of Engineering and Technology, Asian Institute of Technology, Pathumthani, Thailand
Published online: 08 Jan 2015.

International Journal of Occupational Safety and Ergonomics (*JOSE*) 2014, Vol. 20, No. 3, 463–475

A System for Predicting Musculoskeletal Disorders Among Dental Students

Bhornsawan Thanathornwong

Faculty of Dentistry, Srinakarinwirot University, Bangkok, Thailand

Siriwan Suebnukarn

Faculty of Dentistry, Thammasat University, Pathumthani, Thailand

Kan Ouivirach

School of Engineering and Technology, Asian Institute of Technology, Pathumthani, Thailand

Objective. *This study aimed to develop a system for predicting work-related musculoskeletal disorders (WMSD) among dental students.* ***Materials and methods.*** *The system comprised 2 accelerometer sensors to register neck and upper back postures and movements, and software developed to collect and process the data. Hidden Markov models (HMMs) were used to predict the likelihood of WMSD in dental students by comparing their neck and upper back movement patterns with WMSD and non-WMSD HMMs learned from previous data. To evaluate the performance of the system, 16 participants were randomly assigned into a 2 × 2 crossover trial scheduled for each sequence of working: receiving feedback or no-feedback from the system. The primary outcome measure was the extension of the neck and upper back, before (pre-test) and after (post-test) receiving feedback or no-feedback from the system. The secondary outcome measure was the log likelihood of classifying the movements as WMSD.* ***Results and discussion.*** *The results showed that in the group that received feedback, the extension of the neck in the* y *axis and of the upper back in the* y *axis decreased significantly (*t *test,* $p < .05$*) on the post-test.* ***Conclusion.*** *The system for predicting and preventing WMSD aids the correction of the extension of the neck and upper back in the* y *axis.*

musculoskeletal disorders prediction model hidden Markov models dental students

1. INTRODUCTION

Work-related musculoskeletal disorders (WMSD) is the name the U.S. Occupational Safety and Health Administration uses to describe a type of injury that results from chronic overuse or misuse of soft tissues during work [1]. Due to highly concentrated work and restriction of the oral cavity, dentists may stay in a static or awkward posture for a long time. Prolonged static and awkward postures tend to decrease blood supply to the area and overload the supporting soft tissue structures, thus causing pain and discomfort. Dentists frequently assume prolonged static and awkward postures, which require over 50% of the body's muscles to contract to hold the body motionless while resisting gravity. The static forces resulting from these postures have been shown to be much more taxing than dynamic forces [2].

The authors are grateful to all general dentists who joined this study. This study was supported by the Thailand Office of Higher Education Commission, National Research Council of Thailand and Thailand Research Fund.

Correspondence should be sent to Siriwan Suebnukarn, Faculty of Dentistry, Thammasat University, Pathumthani, Thailand. E-mail: siriwan.suebnukarn@gmail.com.

The musculoskeletal health of dental professionals has been the subject of numerous studies worldwide, which focused on the pain experienced by the practitioner. Several studies found that 65%–81% of dentists complained of WMSD [3, 4, 5, 6, 7]. A study among dentists in Queensland, Australia, reported the prevalence of neck- and shoulder-related pain as 58% and 53%, respectively [8]. In Nepal, the results from interviewing 68 dentists showed that neck pain (59%) and shoulder pain (47%) were the most frequent complaints [9]. A survey from Canada found that 62% of dentists had suffered from neck pain sometime in their lives [10]. In a study that used a multidisciplinary approach, 42% of professionally active dentists had experienced pain and interference with daily activities from neck and shoulder problems during the preceding year [11].

According to Rising, Bennett, Hursh, et al., over 70% of dental students reported neck, shoulder and lower back pain by their third year of dental school [12]. Although studies on WMSD among dental students are quite limited [12, 13, 14, 15], many risk factors have been identified, including static and awkward posture and work practices. Overall, previous studies suggested that musculoskeletal problems represented a significant burden for the dental profession. More research is urgently required to help more clearly elucidate the development of this important issue for dental students. Generally, dental students have no guidance, other than a manual on how to handle instruments to perform dental procedures, to assist them with correct neck and upper back postures and movements [12, 13, 14, 15]. The value of this study is that no previous study has shown what kind of method dental students could employ to monitor their own neck and upper back movements to help them self-correct extreme postures and movements to minimize the risk of acquiring WMSD. Consequently, there is a need for a reliable and valid observational instrument that can be used to document and assess parameters of posture and actions of the neck and upper back, which are risk factors for musculoskeletal disorders of the upper extremities, and to assist dental students with correct neck and upper back postures and movements.

2. AIM

In this paper, we present a system for predicting WMSD among dental students by providing information on the risk of WMSD. The system comprised accelerometer sensors to register neck and upper back postures and software developed to collect and process the data. Hidden Markov models (HMMs) were used to model postures, and to predict the likelihood of WMSD in dental students. The system was implemented and evaluated for its potential to be a training tool among dental students. Although the configuration of several body segments is important in dental care, this study focused on neck and upper back postures. Monitoring wrist and hand postures might not be practical as current devices could interfere with dental procedures.

3. METHOD

3.1. System Development

The prototype system was an integrated solution for recording neck and upper back movement range in dentists. The movements to be investigated included flexion and extension, and left and right lateral flexion of the neck and upper back during dental operations to assist in predicting individuals prone to WMSD. This system encouraged dental students to correct neck and upper back movements themselves. The system comprised several components: accelerometer sensors to register neck and upper back postures and movements, and software developed to collect and process the data (Figure 1). HMMs were used to predict whether a dental student was likely to acquire WMSD by comparing the student's neck and back movement patterns with WMSD and non-WMSD HMMs learned from previous data (pilot study).

3.2. Electronic Instrument

The instrumentation consisted of an electronic system that produced a voltage signal in reaction to neck and upper back movements. The sensor used was an ADXL 345 three-axis accelerometer (from Analog Devices, USA) with high resolution

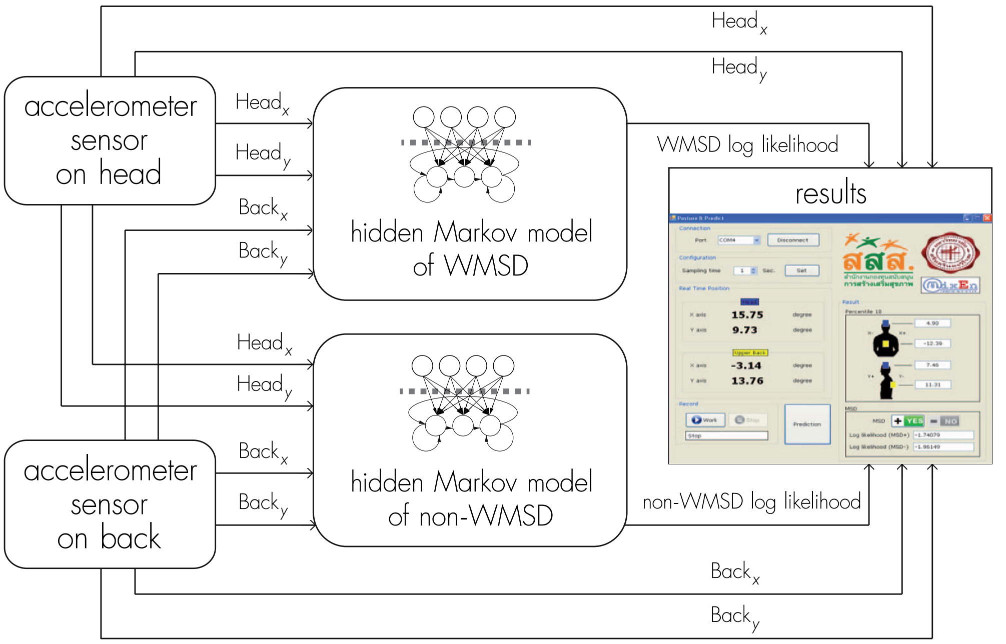

Figure 1. System overview.

(13-bit) measurement at up to ±16 g and a bandwidth response of 12.5–400, Hz. Two accelerometer sensors were used to track neck and upper back movements. Each accelerometer sensor presented two reading outputs, one for X_{out}, the other for Y_{out}, and a power supply voltage input of 2.0–3.6 V. The expected values for X_{out} and Y_{out} were in the digital input/output voltage range of 1.8–2.5 V. The sensor consisted of a structure with a capacitive sensing cell (g-cell) and signal conditioning to detect small displacements. The signals from the accelerometer sensors were amplified and converted into digital signals through a data acquisition card (13-bit resolution) connected to a laptop (Core 2 Duo, Microsoft® Windows XP). The accelerometer mounted on a circuit card was used as an inclinometer to calculate neck and upper back angles during system evaluation.

The software was developed using Visual Studio 2012[1] to control and process the arrival of the signals obtained through flash memory to the computer. The software configured the entrance channels and was programmed considering the pins where the sensors had been connected to the data acquisition card through the analogue signal interface cable. As soon as the signals arrived at the acquisition card, they were available in their respective channels. The voltage was used with the calibration values to obtain the values of flexion–extension for the neck and upper back (in degrees). Results from data processing were stored in a database.

3.3. Pilot Study

We conducted a pilot study to develop HMMs to classify neck and upper back movement patterns of dentists as WMSD or non-WMSD. The training data were obtained from 50 general dentists. Thirty dentists were identified as WMSD, and 20 as non-WMSD according to Kroemer's guidelines [16]. Kroemer's guidelines classify WMSD into three stages: stage 1 is characterized by local aches and tiredness during working time, which usually abate overnight and with days away from work; stage 2 has symptoms of tenderness, swelling, numbness and pain that start early in the work shift and do not abate overnight; stage 3 is characterized by symptoms that persist at rest and during the night. In our study, stages 2–3 were considered as WMSD and stage 1 or no symptoms were considered as non-WMSD. The

[1] http://www.visualstudio.com/

operation selected for our study was scaling on the upper right quadrant of patients with mild gingivitis during their routine schedule. During the work, we continuously stored data on right and left lateral flexion, and flexion and extension of the neck ($Neck_x$ and $Neck_y$) and upper back ($Back_x$ and $Back_y$).

In our system, the four stages ($Neck_x$, $Neck_y$, $Back_x$ and $Back_y$) of neck and upper back movements were the hidden states. We converted these feature vectors into symbols using the k-means clustering algorithm with $k = 13$. In the experiment, we used a discrete HMM that took discrete observations as input, so we needed to convert the feature vectors into symbols. To convert the feature vectors, we first performed k-means clustering and represented each cluster as one symbol, then mapped the feature vectors to each symbol based on the Euclidean distance. We empirically selected the number of clusters $k = 13$.

According to Rabiner, three elements should be defined to specify HMM (λ): (a) the state transition probability distribution matrix A among $Neck_x$, $Neck_y$, $Back_x$ and $Back_v$ that characterize WMSD; (b) the observation symbol probability distribution matrix B (in our study the observation symbols were WMSD and non-WMSD); and (c) the initial state distribution vector π [17]. The HMM can thus be defined by $\lambda = (A, B, \pi)$. We trained the WMSD and non-WMSD HMMs by adjusting the model parameters (A, B, π) to maximize the probability (P) of the training sequence as follows:

given: $\lambda = (A, B, \pi)$,
adjust: A, B, π,
maximize: $P(O|\lambda)$,

where λ = hidden Markov models; A, B = probability distribution matrixes; π = initial state distribution vector; P = probability; O = observation.

After training the models, we computed the probability of the observation sequence, given the model and the observation (O) sequence as follows:

given: $\lambda = (A, B, \pi)$, $O = o_1, o_2, o_3, \ldots, o_t$,
compute: $P(O|\lambda)$,

where λ = hidden Markov models; A, B = probability distribution matrixes; π = initial state distribution vector; O = observation; $o_1, \ldots, o_t$ = observation 1, … , observation t; P = probability.

We calculated the probability and log likelihood of the test movements under the WMSD and non-WMSD HMMs. The likelihood of an observation sequence was computed using the forward algorithm [17]. If the log likelihood of the test movement sequence under WMSD HMM was greater than that under the non-WMSD HMM, the system classified the test movement sequence as WMSD; otherwise, it classified it as non-WMSD. The time increment between the successive equidistant steps during training, testing and using the model was $Neck_x$/s, $Neck_y$/s, $Back_x$/s and $Back_y$/s. One movement sequence took 5 min.

3.4. System Evaluation

After the electronic instrumentation and software were developed, the following procedure was established for system evaluation. We conducted a randomized 2 × 2 crossover trial at a student clinic to compare the effectiveness of using the system over routine dental work with no feedback from the system.

3.5. Study Population

Sixteen dental students (14 females and 2 males) aged 21–23 years were recruited. The choice of at least 16 participants per group was based on a two-tailed test, with $\alpha = .05$ and power $(1 - \beta) = .80$. The inclusion criteria were that the participants performed a minimum of 6 h of dental work a day. They were not admitted to the study if they received a score under 70% in an assessment of knowledge of dental ergonomics. The participants filled in a questionnaire about their health and workplace. None of them were excluded from the group on health grounds. All participants gave their written informed consent approved by the institutional ethical committee.

3.6. Experimental Design

The study was conducted in a student periodontal clinic. The participants' task was to perform scaling on upper right maxillary second and first molars. The primary outcome measures recorded by our system included the angle (in degrees) at

10th percentile of $Neck_x$, $Neck_y$, $Back_x$ and $Back_y$, accurate to 0.01°. The secondary outcome measure was the log likelihood of classifying the movements as WMSD accurate to 0.01 log likelihood. The participants were randomly assigned into a 2 × 2 crossover trial using a computer-generated randomization schedule for each of two sequences of working. The participants in the experiment group received feedback on those data after finishing scaling on the second molar (feedback), while those in the control group received no feedback (no-feedback). The primary and secondary outcome measures were recorded twice: after finishing scaling on the second molar (pre-test) and after finishing scaling on the first molar (post-test) (Figure 2). Figures 3a and 3b show respective screenshots of the results on the pre- and post-test of one participant. Group A was

(a) (b)

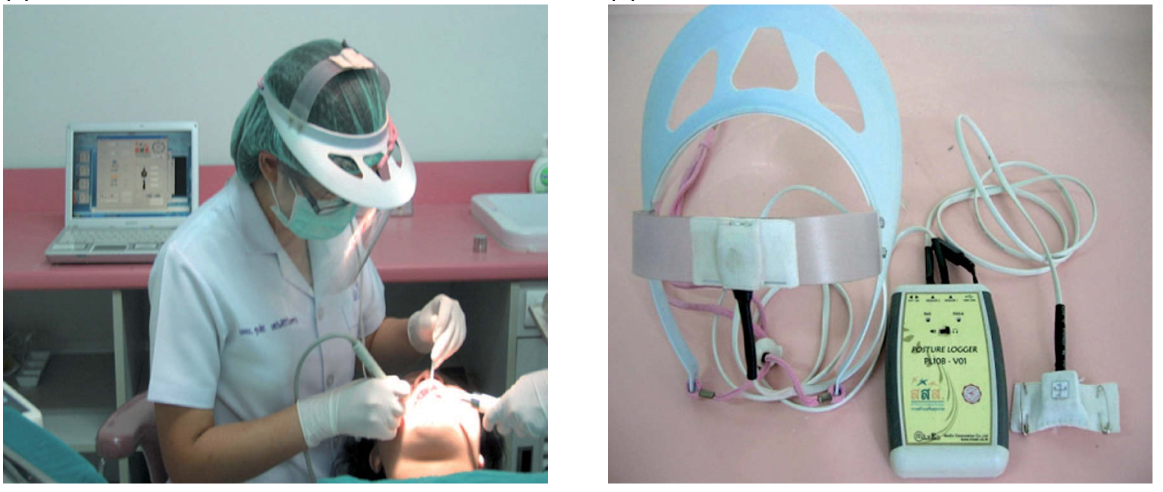

Figure 2. (a) Dental student with accelerometer sensors attached to the face shield and gown on the back; (b) equipment.

Figure 3a. View of screen with system results exhibited in an integrated manner: after finishing scaling on 2nd molar (pre-test).

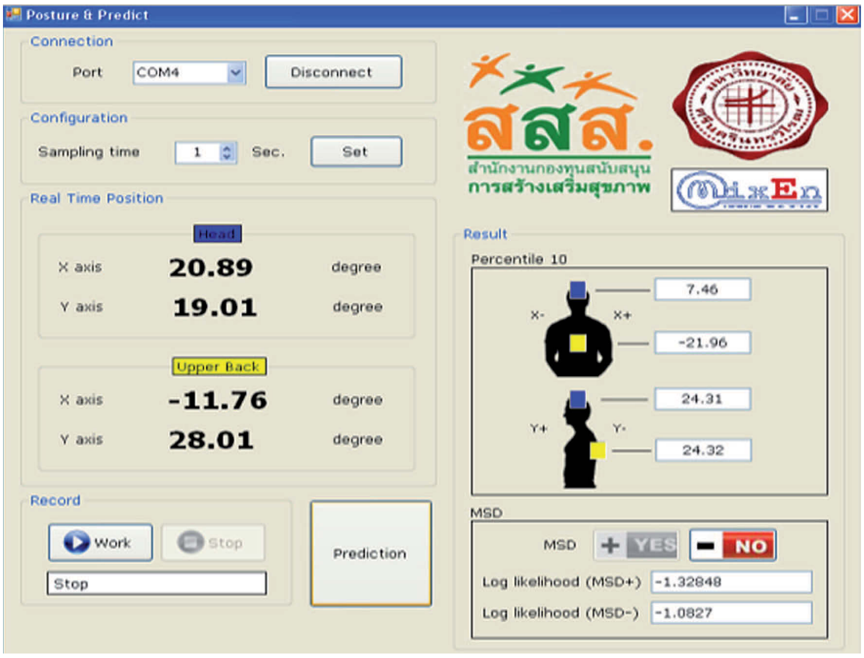

Figure 3b. View of screen with system results exhibited in an integrated manner: after finishing scaling on 1st molar (post-test).

assigned to an initial testing session receiving system feedback followed by receiving no feedback in the second testing session. Group B was assigned to an initial testing session receiving no feedback followed by receiving system feedback in the second testing session (Figure 4).

3.7. Statistical Analysis

The mean values for the dependent variables of $Neck_x$, $Neck_y$, $Back_x$ and $Back_y$, and WMSD likelihood were compared between pre- and post-test within the same group and the differences between the feedback and no-feedback groups with the dependent t test. The data were approximately normally distributed. SPSS version 15.0 was used, with results reported as median values and $p < .05$ considered statistically significant.

4. RESULTS

Tables 1–2 show the 10th percentile of neck and upper back movements in the x and y axes, and the log likelihood of classifying the movements as WMSD comparing pre- and post-test of the no-feedback group in each participant. The results for the participants that received no feedback from the system regarding the angle at 10th percentile of $Head_x$, $Head_y$, $Back_x$, $Back_y$, were not statistically different ($p > .05$) in the neck and upper back movements in the x and y axes, and the log likelihood of classifying the movements as WMSD comparing between pre- and post-test (Figure 5). The participants that received feedback from the system significantly decreased ($p < .05$) the extension of the neck and the upper back in the y axis on the post-test (Figure 6).

	testing session 1	washout	testing session 2
group A	pre-test → feedback → post-test (n = 8)	╳	pre-test → feedback → post-test (n = 8)
group B	pre-test → no-feedback → post-test (n = 8)		pre-test → no-feedback → post-test (n = 8)

Figure 4. Crossover study with 16 participants (groups A and B). *Notes.* After a washout period of 2 weeks, participants were retested on the same dental procedures but with feedback or no-feedback from the system, including angle at 10th percentile of $Head_x$, $Head_y$, $Back_x$ and $Back_y$; and the log likelihood of classifying movements as work-related musculoskeletal disorders (WMSD). Testing sequence of group A: feedback, no-feedback; testing sequence of group B: no-feedback, feedback.

TABLE 1. Summary Table of 16 Participants' Changes From Pre- to Post-Test During Conventional Intervention

	Pre-Test				
Participant	$Neck_x$	$Neck_y$	$Back_x$	$Back_y$	WMSD+
1	–7.15	15.07	1.57	1.85	–1.77
2	–5.14	52.65	–18.59	12.71	–1.73
3	–22.06	11.10	–10.55	18.44	–1.55
4	–13.81	19.69	1.51	18.90	–1.67
5	–1.06	10.46	–1.54	16.34	–1.56
6	4.64	28.14	0.45	27.82	–2.28
7	–18.1	4.33	–4.58	13.63	–1.54
8	–8.61	1.80	4.47	13.77	–2.35
9	–18.12	19.96	–12.68	24.29	–1.61
10	–22.73	4.74	–16.71	14.21	–1.57
11	7.49	7.04	–19.31	23.04	–1.06
12	3.47	28.29	–15.79	15.69	–1.96
13	2.33	7.19	–12.74	15.31	–2.95
14	8.29	23.44	–13.31	22.98	–2.13
15	5.94	30.59	–13.69	31.41	–2.14
16	17.82	15.9	–16.08	26.85	–2.79
M (*SD*)	–4.17 (12.22)	17.52 (13.11)	–9.22 (8.13)	18.57 (7.28)	–1.92 (0.49)

	Post-Test				
Participant	$Neck_x$	$Neck_y$	$Back_x$	$Back_y$	WMSD+
1	–5.87	42.43	0.79	17.04	–1.58
2	–16.84	33.68	–11.33	2.30	–1.94
3	–23.45	21.46	–8.10	24.47	–1.59
4	–15.32	25.15	–2.04	20.81	–1.56
5	5.60	23.01	2.34	22.90	–1.36
6	0.49	22.64	–0.51	23.95	–1.89
7	–15.28	10.31	–6.44	22.66	–1.53
8	–16.33	15.92	–0.55	9.72	–1.60
9	–15.59	20.44	–11.34	23.47	–1.61
10	–23.11	5.79	–17.61	15.56	–1.56
11	4.16	27.90	–8.23	7.07	–3.49
12	3.37	18.83	–17.82	19.27	–2.09
13	14.36	27.8	–14.36	19.35	–2.15
14	8.22	8.96	–15.57	18.73	–1.30
15	0.55	8.63	–20.67	15.01	–2.12
16	0.43	6.65	–16.32	24.35	–2.15
M (*SD*)	–5.91 (11.98)	19.97 (10.33)	–9.23 (7.51)	17.91 (6.60)	–1.85 (0.52)

Notes. $Neck_x$ = flexion of neck, $Neck_y$ = extension of neck, $Back_x$ = flexion of upper back, $Back_y$ = extension of upper back, WMSD+ = likelihood of classifying movements as WMSD.

TABLE 2. Summary Table of 16 Participants' Changes From Pre- to Post-Test Following Using the System

	Pre-Test				
Participant	**$Neck_x$**	**$Neck_y$**	**$Back_x$**	**$Back_y$**	**WMSD+**
1	–10.83	29.68	–16.29	19.09	–1.56
2	–6.81	15.52	7.12	18.31	–1.67
3	–22.83	21.17	–7.72	22.96	–1.55
4	–14.00	23.40	–1.53	20.48	–1.5
5	9.10	25.13	0.25	18.25	–0.88
6	1.19	26.42	–0.78	29.05	–1.57
7	–22.57	10.85	–11.9	15.05	–1.51
8	–15.64	6.98	5.73	16.60	–1.43
9	–23.23	24.36	6.89	28.85	–0.46
10	–14.09	4.93	–12.24	14.85	–0.24
11	9.40	6.59	–19.93	23.99	–1.06
12	4.90	7.46	–12.39	11.31	–1.74
13	17.10	23.21	–12.81	26.31	–1.33
14	1.64	23.58	–15.87	28.6	–1.78
15	0.24	3.39	–13.3	31.56	–3.40
16	23.02	14.95	–13.95	26.84	–1.51
M (*SD*)	–3.96 (14.47)	16.72 (8.88)	–7.42 (8.97)	22.00 (6.1)	–1.45 (0.68)

	Post-Test				
Participant	**$Neck_x$**	**$Neck_y$**	**$Back_x$**	**$Back_y$**	**WMSD+**
1	–6.59	10.42	0.51	10.38	–1.78
2	–9.25	15.78	40.08	10.75	–1.96
3	–21.13	19.81	–8.30	18.75	–1.63
4	–14.23	21.03	0.67	19.04	–1.68
5	–1.06	10.46	–1.54	16.34	–1.56
6	–7.63	15.01	7.26	22.63	–3.14
7	–5.58	7.57	–7.47	2.34	–1.99
8	–17.44	5.97	8.95	8.92	–2.43
9	–18.78	16.11	–13.51	2.90	–1.63
10	–27.4	1.94	–19.00	5.19	–1.65
11	6.17	2.46	–12.58	10.91	–1.06
12	7.46	24.31	–21.96	24.32	–1.32
13	5.14	1.29	–14.37	14.84	–1.68
14	–0.43	5.69	–15.83	9.50	–1.57
15	9.14	4.79	–15.35	17.13	–1.36
16	12.86	5.63	–11.92	10.34	–1.03
M (*SD*)	–5.54 (11.98)	10.51 (7.29)	–5.27 (15.14)	12.76 (6.58)	–1.72 (0.51)

Notes. $Neck_x$ = flexion of neck, $Neck_y$ = extension of neck, $Back_x$ = flexion of upper back, $Back_y$ = extension of upper back, WMSD+ = likelihood of classifying movements as WMSD.

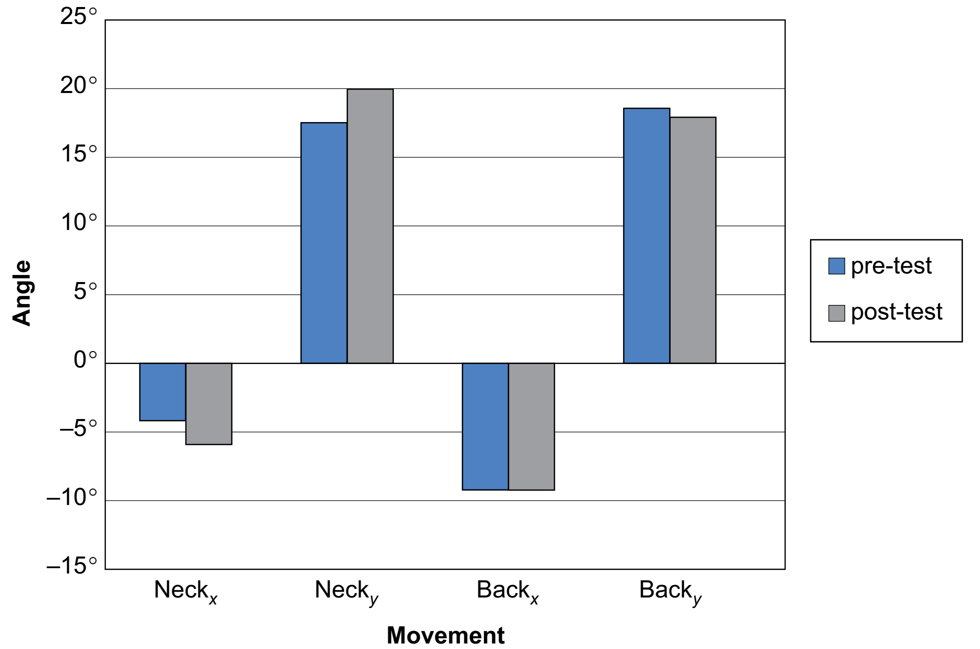

Figure 5. Mean 10th percentile of neck and upper back movements, and log likelihood of classifying movements as work-related musculoskeletal disorders (WMSD) comparing between pre- and post-test of no-feedback group. Notes. Neck$_x$ = flexion of neck, Neck$_y$ = extension of neck, Back$_x$ = flexion of upper back, Back$_y$ = extension of upper back.

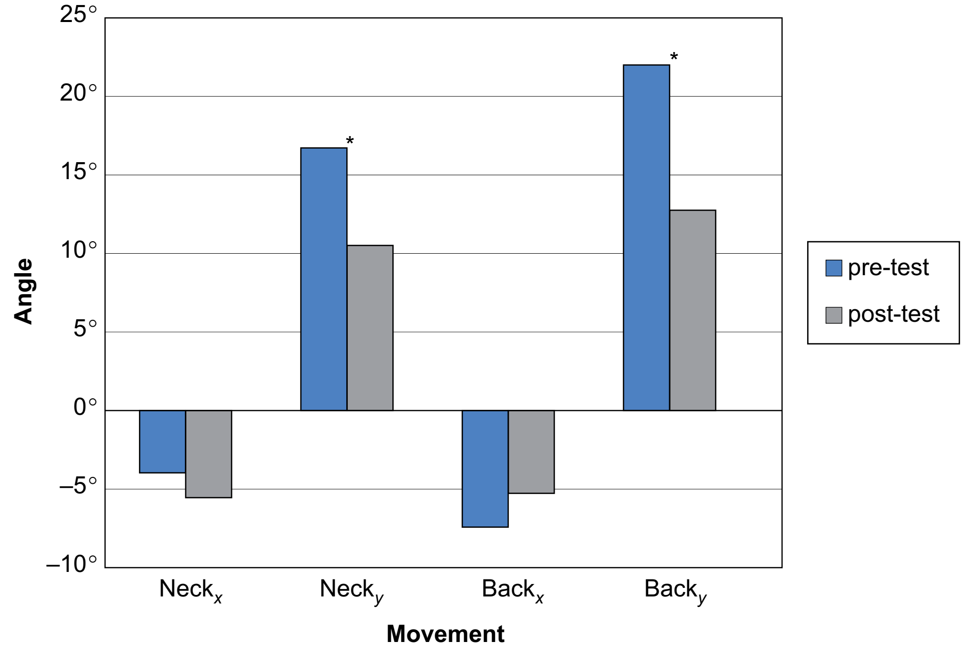

Figure 6. Mean 10th percentile of neck and upper back movements, and log likelihood of classifying movements as work-related musculoskeletal disorders (WMSD) comparing between pre- and post-test of feedback group. *Notes*. * = Neck$_y$ and Back$_y$ on post-test decreased significantly (*t* test, $p < .05$); Neck$_x$ = flexion of neck, Neck$_y$ = extension of neck, Back$_x$ = flexion of upper back, Back$_y$ = extension of upper back.

5. DISCUSSION

Several types of ergonomic assessment have been developed to detect risk factors that might result in WMSD [18]. In dental care, posture-based methods have been widely used to detect WMSD among dentists. Those methods can be classified as observational, direct and self-reporting [19, 20, 21]. Observational methods have been used to assess dental activities via films, photographs or videotapes. Marklin amd Cherney measured the gross posture of 10 dentists using videotapes [22]. They found that dentists bent their neck at least 30° ~85% of the time they were working on patients. Limitations of observational methods have been reported, including the need for trained evaluators to observe dentists' working conditions, questionable reliability, the halo effect and errors of leniency and severity [23]. Direct methods have used manual devices or electronic equipment (electrogoniometers, accelerometers, etc.) to evaluate exposure to risk by measuring postural and muscular conditions, motion, force and body angles [18]. Akesson, Hansson, Balogh, et al. used an accelerometer to record forward and sideways bending [24]. They found that 90% of the time (10th percentile), the head was forward tilted ≥17°, 50% of the time it was tilted ≥39° and 10% it was tilted ≥49°. However, these methods have been generally expensive, complicated and not appropriate for quantifying dentists' range of movements. Self-reporting methods have been mainly used to assess levels of physical work load, body discomfort or work stress. Self-reporting methods, e.g., rapid upper limb assessment (RULA), have provided valuable insight into working conditions not accomplished by any other methods, and have been able to provide information in sufficient quantity for very large case–control or cohort studies [23, 25, 26, 27]. Self-assessment has been successfully used in epidemiological studies to collect information associated with musculoskeletal discomfort. However, disadvantages of self-reporting methods have been reported, including low validity, low reliability or both, in relation to the needs of and requirements for ergonomic assessments [19]. For these reasons, we selected a direct method with accelerometer sensors used to quantify the range of the movements during dental operations.

The design of our system provided the capacity to measure movements of the neck and upper back, and to use these data to predict the likelihood of WMSD. Our electronic instrument allowed the discovery of vulnerabilities in dentists' posture that might cause WMSD. Re-education in the way that these movements are accomplished is an important factor in preventing these complaints. In our study, the prediction model data were obtained from 50 general dentists, and the main study was conducted in 16 young dental students. We were aware that there could be differences in the results between these groups, considering the differences in age, experience, specialization, regular practice of physical exercise and possible experience of some WMSD-related pathology. However, as we can draw from previous work, there was a strong relationship between neck musculoskeletal disorders and high levels of static contraction, prolonged static loads and extreme working postures involving neck and shoulder muscles [28, 29, 30, 31, 32, 33]. Neck and upper back postures during dental work should be close to the natural position of the spine. Chaffin, Andersson and Martin provided a basis for a recommendation not to exceed 30° of flexion over sustained periods [28]. The RULA method of assessing workstations considered neck flexion to be of progressively greater risk over 10° and assigned the highest risk level to any amount of extension [29]. Andersen, Kaergaard, Mikkelsen, et al. [30] and Andersen, Kaergaard, Frost, et al. [31] also found an exposure response relation between the proportion of cycle time and the neck flexed over 20°, the rate ratios being raised significantly (1.7- to 2.6-fold) in a clinical case. Indirect support for these findings came from a study in which constrained neck posture with neck flexion seemed likely given the nature of the work [32]. Fagarasanu and Kumar gave several reasons for maintaining neck posture near the neutral zone [23]. WMSD are the major cause of problems which lead to early retirement of dentists [33]. An increase in neck inclination of 30°–60° causes a decrease in the time of reaching fatigue in neck muscles from 5 to 2 h [28]. Besides working in postures with the neck flexed over 20°, neck flexion has been associated with an increase in neck pain. The forward head and rounded shoulders posture also increases forces on upper neck muscles (upper trapezius and levator scapulae) and spinal vertebral discs [2]. Forward head posture may precede the tension neck syndrome, precipitating muscle imbalances, ischemia, trigger points, cervical disc degeneration or herniation.

When the human body is subjected repeatedly to prolonged static postures, it can initiate a series of events that may result in pain, injury or career-ending WMSD [33]. Since the electronic instrument for predicting WMSD proposed in this study can identify improper posture during routine dental work, it should also be able to help prevent WMSD resulting from awkward posture. The declination of neck and back angles in flexion direction among dental students that received feedback regarding their neck and back movements, including a reminder of the likelihood of WMSD, was a positive effect of the system.

The skills and muscle memory that students develop during their clinical education are the basis for their future career. However, knowledge of ergonomics might not result in correct posture during clinical procedures [34]. A poor understanding of ergonomics theory, a gap between the theoretical discipline and its clinical application and a working environment unsuitable for ergonomically correct dental work may interfere in learning ergonomics principles. In this sense, it is necessary to improve the teaching and learning environment in dental ergonomics. The positive results of our study show the system can assist dental students with correct neck and upper back postures and movements during dental work. Although the implementation of this system may require an initial investment in terms of software, costs must be balanced against those of traditional training. With this in mind, this system is an option as it requires little running cost and, once bought, it is always available and can be repeatedly used for skills training. It is important that in this study WMSD were predicted using only working postures and movements of the neck and upper back. A further study should investigate the improvement in the time required and the quality of work, in which the system is used and the long term effects on dentists' routine work. Other contributing factors could be incorporated in building the prediction model, e.g., individual and other psychosocial factors.

In summary, the system for predicting musculoskeletal disorders aids the correction of the extension of the neck and upper back in dental students, which may potentially contribute to reducing the risk of injury due to inappropriate posture. It can also be used as an ergonomics training tool for dental students.

REFERENCES

1. Aptel M, Aublet-Cuvelier A, Cnockaert JC. Work-related musculoskeletal disorders of the upper limb. Joint Bone Spine. 2002;69(6): 546–55.
2. Valachi B, Valachi K. Mechanisms leading to musculoskeletal disorders in dentistry. J Am Dent Assoc. 2003;134(10):1344–50.
3. Shugars D, Miller D, Williams D, Fishburne C, Strickland D. Musculoskeletal pain among general dentists. Gen Dent. 1987;35(4): 272–6.
4. Rundcrantz BL, Johnsson B, Moritz U. Cervical pain and discomfort among dentists. Epidemiological, clinical and therapeutic aspects. Part 1. A survey of pain and discomfort. Swed Dent J. 1990;14(2): 71–80.
5. Finsen L, Christensen H, Bakke M. Musculoskeletal disorders among dentists and variation in dental work. Appl Ergon. 1998;29(2):119–25.
6. Chowanadisai S, Kukiattrakoon B, Yapong B, Kedjarune U, Leggat PA. Occupational health problems of dentists in southern Thailand. Int Dent J. 2000;50(1):36–40.
7. Marshall ED, Duncombe LM, Robinson RQ, Kibreath SL. Musculoskeletal symptoms in New South Wales dentists. Aust Dent J. 1997;42(4):240–6.
8. Leggat PA, Smith DR. Musculoskeletal disorders self-reported by dentists in Queensland, Australia. Aust Dent J. 2006; 51:324–327.

9. Shrestha BP, Singh GK, Niraula SR. Work related complaints among dentists. JNMA J Nepal Med Assoc. 2008;47(170):77–81.
10. Bassett S. Back problems among dentists. J Can Dent Assoc. 1983;49(4):251–6.
11. Lehto TU, Helenius HY, Alaranta HT. Musculoskeletal symptoms of dentists assessed by a multidisciplinary approach. Community Dent Oral Epidemiol. 1991; 19(1):38–44.
12. Rising DW, Bennett BC, Hursh K, Plesh O. Reports of body pain in a dental student population. J Am Dent Assoc. 2005;136(1): 81–6.
13. Thornton LJ, Barr AE, Stuart-Buttle C, Gaughan JP, Wilson ER, Jackson AD, et al. Perceived musculoskeletal symptoms among dental students in the clinic work environment. Ergonomics. 2008;51(4): 573–86.
14. de Carvalho MV, Soriano EP, de França Caldas A Jr, Campello RI, de Miranda HF, Cavalcanti FI. Work-related musculo-skeletal disorders among Brazilian dental students. J Dent Educ. 2009;73(5):624–30.
15. Hayes M, Cockrell D, Smith DR. A systematic review of musculoskeletal disorders among dental professionals. Int J Dent Hyg. 2009;7(3):159–65.
16. Kroemer KHE. Ergonomic design of material handling systems. Boca Raton, FL, USA: Lewis; 1997.
17. Rabiner LR. A tutorial on hidden Markov models and selected application in speech recognition. Proceedings of the IEEE. 1989;77(2):257–86.
18. Halpern M. Job and task analysis. In: Murphy DC, editor. Ergonomics and the dental care worker. Washington, DC, USA: American Public Health Association; 1998. p. 83–112.
19. Li G, Buckle P. Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. Ergonomics. 1999; 42(5):674–95.
20. Dempsey PG, McGorry RW, Maynard WS. A survey of tools and methods used by certified professional ergonomists. Appl Ergon. 2005;36(4):489–503.
21. Winnemuller LL, Spielholz PO, Daniell WE, Kaufman JD. Comparison of ergonomist, supervisor, and worker assessments of work-related musculoskeletal risk factors. J Occup Environ Hyg. 2004;1(6):414–22.
22. Marklin RW, Cherney K. Working postures of dentists and dental hygienists. J Calif Dent Assoc. 2005;33(2):133–6.
23. Faragasanu M, Kumar S. Measurement instruments and data collection: a consideration of constructs and biases in ergonomics research. Int J Ind Ergon. 2002;30(6):355–369.
24. Akesson I, Hansson GA, Balogh I, Moritz U, Skerfving S. Quantifying work load in neck, shoulders and wrists in female dentists. Int Arch Occup Environ Health. 1997;69(6):461–74.
25. Marley RJ, Kumar N. An improved musculoskeletal discomfort assessment tool. Int J Ind Ergon. 1996;17(1):21–7.
26. Ramsay GF. Using self-administered work sampling in a state agency. Ind Eng. 1993;25:44–5.
27. Chaikumarn M. Differences in dentists' working postures when adopting proprioceptive derivation vs. conventional concept. International Journal of Occupational Safety and Ergonomics (JOSE). 2005;11(4):441–9. Retrieved June 25, 2014, from: http://www.ciop.pl/15245.
28. Chaffin DB, Andersson GBJ, Martin BJ. Occupational biomechanics. 3rd ed. New York, NY, USA: Wiley; 1999.
29. McAtamney L, Corlett EN. RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon. 1993;24(2):91–9.
30. Andersen JH, Kaergaard A, Mikkelsen S, Jensen UF, Frost P, Bonde JP, et al. Risk factors in the onset of neck/shoulder pain in a prospective study of workers in industrial and service companies. Occup Environ Med. 2003;60:649–54. Retrieved June 25, 2014, from: http://oem.bmj.com/content/60/9/649.full.pdf+html.
31. Andersen JH, Kaergaard A, Frost P, Thomsen JF, Bonde JP, Fallentin N, et al. Physical, psychosocial, and individual risk factors for neck/shoulder pain with pressure

tenderness in the muscles among workers performing monotonous, repetitive work. Spine (Phila Pa 1976). 2002;27(6):660–7.

32. Akesson I, Johnsson B, Rylander L, Moritz U, Skerfving S. Musculoskeletal disorders among female dental personnel—clinical examination and a 5-year follow-up study of symptoms. Int Arch Occup Environ Health. 1999;72(6):395–403.

33. Brown J, Burke FJ, Macdonald EB, Gilmour H, Hill KB, Morris AJ, et al. Dental practitioners and ill health retirement: causes, outcomes and re-employment. Br Dent J. 2010;209(5):E7.

34. Garbin AJÍ, Garbin CAS, Diniz DG, Yarid SD. Dental students' knowledge of ergonomic postural requirements and their application during clinical care. Eur J Dent Educ. 2011;15(1):31–5.