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The Improvement of Dental Posture Using Personalized Biofeedback

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Abstract

Background: Dentists are subject to staying in static or awkward postures for long periods due to their highly concentrated work. Objectives: This study describes a real-time personalized biofeedback system developed for dental posture training with the use of vibrotactile biofeedback. Methods: The real-time personalized biofeedback system was an integrated solution that comprised of two components: 1) a wearable device that contained an accelerometer sensor for measuring the tilt angle of the body (input) and provided real-time vibrotactile biofeedback (output); and 2) software for data capturing, processing, and personalized biofeedback generation. The implementation of real-time personalized vibrotactile feedback was computed using Hidden Markov Models (HMMs). For the test case, we calculated the probability and log-likelihood of the test movements under the Work related Musculoskeletal Disorders (WMSD) and non-WMSD HMMs. The vibrotactile biofeedback was provided to the user via a wearable device for a WMSD-predicted case. In the system evaluation, a randomized crossover trial was conducted to compare dental posture measure using tilt angles of the upper back and muscle activities of those dental students that received vibrotactile biofeedback from the system with the control group against the dental students who received no feedback. Results: The participants who received feedback from the system had a lower tilt angle at 10^{th}, 50^{th}, and 90^{th} percentiles of $Back_x$ and $Back_y$, as well as muscular load, which were statistically different ($p < 0.05$) from those who received no feedback from the system. Conclusions: The results presented here demonstrate that a personalized biofeedback system for posture training in dental students is feasible and associated with quantitative improvements of the dental posture.

Keywords:

Hidden Markov Model; Musculoskeletal disorders; Vibrotactile biofeedback; Personalization.

Introduction

A large number of dentists suffer from musculoskeletal problems later in their professional lives. Some dentists have milder forms of musculoskeletal problems, while others have much more severe forms. A proportional correlation between the number of disorders and the years of clinical experience have been reported.[1] Dentists are subject to staying in static or awkward postures for long periods due to their highly concentrated work and the restriction of the oral cavity. According to Rising et al.,[2] more than 70 percent of dental students reported neck, shoulder, and lower back pain by their third year of dental school. In order to prevent this; correct dentist posture must be established early among dental students. Therefore, the correct posture must be stressed in dental schools. Although most schools teach the correct and ideal dentist posture and positions, they are not always applied by the dental students themselves.

A complex interplay of feedback and feed-forward control ensures the natural ability of the human body to maintain an upright stance, and to stabilize during movement.[3] One approach to improving balance which has been widely used in physical therapy and rehabilitation involves feeding back to the central nervous system supplementary environmental information about body motion. This supplemental information may come from a therapist, laboratory equipment, or artificial sensors.[4] Biofeedback (BF) systems for postural control are aimed at providing additional sensory information to supplement natural sensory information and improve human balance. Since the experimentation of biofeedback systems for postural control began, tactile and audio biofeedback have received much less attention than visual biofeedback. Nevertheless, in the last few years, interest in tactile- and audio-biofeedback systems for postural control has been renewed,[5,6] partially due to advances in technology for real-time processing and movement sensing, and to new trends in wireless wearable devices that can be worn during daily activities. Audio-biofeedback experimentation was carried out by Chiariet et al. [6] and Hegeman et al., [7] who developed audio BF devices able to encode trunk movement information into a sound. In 2001, Wall et al. [5] developed a device able to provide tactile feedback of trunk tilt by vibrating tactors that the subjects wore around their trunk. This study showed how vibrotactile feedback might improve balance performance in healthy subjects, as well as the possible usefulness and validity of this system as a prosthesis for people with pathologies that impair balance.

The use of biofeedback has been offered in the past as an instrument for training that enables an individual to learn how to change physiological activity or behavior for the purposes of improving performance. In therapeutic applications, biofeedback training of balance and posture has shown to be effective for posture control in adolescent scoliosis,[8] and has also decreased the fall rate in elderly patients with peripheral neuropathy.[9] In patients with bilateral vestibular loss,[10] biofeedback training was also found useful in enhancing postural stability even under challenging standing conditions, beyond the effect of practice alone.[10-12]

The aims of this study were to investigate the manner and tasks in which the personalized biofeedback system can be used to enhance postural control in dental operation, to explore the feasibility of using a personalized biofeedback system for posture training of dental students, and to preliminarily assess the usability and efficacy of a personalized biofeedback paradigm on a group of dental students. This study describes a real-time personalized biofeedback system developed for posture training with the use of vibrotactile biofeedback. The value of this study is that no previous studies have shown how a personalized biofeedback system could be employed by dental students for monitoring their posture, as well as helping them to self-correct their posture and movements in order to minimize the risk of acquiring musculoskeletal problems. Although our focus of attention is in the area of dentistry, the proposed system could be applied to other domains that require self-monitoring and correction of posture.

Methods

Real-time personalized biofeedback system

The real-time personalized biofeedback system was an integrated solution comprised of two components (Figure 1): 1) A wearable device that contained an accelerometer sensor for measuring the tilt angle of the body (input) and provided real-time vibrotactile biofeedback (output). The angles to be measured included: flexion and extension, left and right lateral flexion during the operation. The system took those angles as input to the software. 2) The software was used for tilt angle data capturing, data processing, and personalized biofeedback generation. The implementation of real-time personalized vibrotactile feedback was computed using Hidden Markov Models (HMMs).[13] HMMs were used to predict whether the dental student was likely to acquire Work-related Musculoskeletal Disorders (WMSD) by comparing the dental student's movement patterns with WMSD and non-WMSD HMMs learned from previous data. The vibrotactile biofeedback was provided to the user via a wearable device for a WMSD-predicted case. The idea was to encourage dental students to correct upper back movement themselves after receiving vibrotactile biofeedback during their dental work.

Device

The wearable device developed by our group consisted of an electronic system that produced a voltage signal in reaction to body movements. It consisted of an ADXL345 3-axis accelerometer with high-resolution (13-bit) measurement at up to ±16g and a 12.5-400Hz bandwidth response. An accelerometer sensor was used for tracking body tilt angles. The accelerometer sensor presented two reading outputs, one for the X_{out} and another for Y_{out}, and a power supply voltage input of 2.0-3.6V. The expected values for X_{out} and Y_{out} were in the digital IO voltage range of 1.8-2.5V. 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 computer (Laptop computer with a Core i5 processor, running Microsoft® Windows 7). The accelerometer mounted on a circuit card was used as an inclinometer to calculate body tilt angles during the dental operation (Figure 2).

Software

The software was developed using Visual Studio to control and process the arrival of the signals obtained through a 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 an analogical signal interface cable. As soon as the signals arrived at the acquisition card, they were available in their respective channels. The voltages were used with calibration values in order to obtain the values of flexion/extension of the body tilt in degrees. Results from the data processing were stored in a database.

Figure 1 - Personalized biofeedback system

Figure 2 - The wearable device containing an accelerometer sensor and vibrotactile biofeedback module was attached to the operator's gown to measure the tilt angles of the upper back. The device was lightweight and did not interfere with the dental operation.

Personalized biofeedback

We propose a HMM as a statistical tool to objectively assess dental posture based on the measured data about the operator's tilt angles. HMMs have been used extensively, and have shown to be effective in applications such as gesture recognition [14] and speech recognition.[13] They also have been used for modeling human operator skills and transferring them to robots.[15] Recently, HMMs have been applied to model complex tasks such as surgery (specifically in automatic assessment of surgical performance in laparoscopy),[16] pelvic examination,[17] and mastoidectomy.[18] These applications suggest that HMMs have high potential to provide accurate models for assessing dental posture.

We conducted an experiment to test the ability of a machine learning technique, the HMM, to recognize and classify an observed dentist movement patterns as WMSD or non-WMSD, based on a set of recorded important features. The training data were obtained from fifty general dentists. Thirty dentists were identified as WMSD, and 20 as non-WMSD according to Kroemer's guidelines.[19] Kroemer's guidelines classified WMSD into 3 stages: Stage 1 is characterized by local aches and tiredness during the working hour, which usually abate overnight and with days away from work; Stage 2 has symptoms of tenderness, swelling, numbness and pain that starts early in the work shift and does not abate overnight; Stage 3 is characterized by symptoms that persist at rest and during the night. In our study Stage 2 and 3 were considered to be in the WMSD group and Stage 1 or no symptoms were considered to be in the non-WMSD group. Informed consent was provided upon recruitment to the study. The operation selected for our study was scaling on the upper right quadrant of mild gingivitis patients during their routine schedule. During the work, we continuously stored the data on the right and left lateral flexion, and flexion and extension of the upper back ($Back_x$ and $Back_y$).

Once the models were trained, we calculated the probability and log-likelihood of the test movements under the WMSD and non-WMSD HMMs using the forward algorithm as described previously to find the model that best describes the test movement data. If the log-likelihood of the test movements under WMSD HMM was greater than under the non-WMSD HMMs, the system classified the test movement as WMSD; otherwise, it was classified as non-WMSD. The personalized vibrotactile biofeedback was provided to the user via a wearable device for a WMSD predicted case.

We used discrete HMMs to model the system. To validate the model precision, we performed five-fold cross validation. A different *k*-means clustering algorithm was used for every cross validation fold and the same *k*-means for the WMSD and non-WMSD model in the same fold. For each fold, we trained the WMSD HMM with four WMSD and four non-WMSD sequences. To determine the accuracy of the method, after training the two HMMs in each fold, we fed the test WMSD and non-WMSD data to each model. The average log likelihood of all sequences across all five folds for the two HMMs is shown in Table 1. In every cross validation fold, the log likelihood of every test sequence under its corresponding HMM was higher than that under the other HMM. These results demonstrate the ability of the HMM to distinguish between WMSD and non-WMSD movement with 100% accuracy.

Table 1 - Average log likelihood results for WMSD and non-WMSD movement sequences

	Log likelihood for WMSD HMM	Log likelihood for non-WMSD HMM
WMSD	-3.475×10^3	-2.121×10^6
Non-WMSD	-6.142×10^5	-3.584×10^3

System evaluation

Participants and design

In this study, a randomized crossover trial was conducted to compare tilt angles of the upper back and muscle activities of the participants that received vibrotactile biofeedback from the system with the control group who received no feedback. Upper back tilt angles while performing scaling on upper 1st and 2nd molars were measured. We hypothesized that the participants that received vibrotactile biofeedback from the system will improve their postures (decreased $Back_x$ degree and $Back_y$ degree, and upper trapezius muscle activity). We recruited sixteen dental students (8 females and 8 males) aged between 21 and 23. The choice of at least 16 participants per group was based on a 2-tailed test, with $\alpha = 0.05$ and power $(1-\beta) = 0.80$. The inclusion criteria were that the participants performed a minimum of 6 h of dental practice a day. They were not admitted to the study if they received below 70 percent marks in knowledge assessment of dental ergonomics. Participants answered a questionnaire about their health and workplace. None of them were excluded from the group on health grounds. The study was approved by the institutional Ethical Review Board. A written consent form was provided by all participants. Participants were randomly assigned into a 2x2 crossover trial using a computer–generated randomization schedule to each of two sequences of working. Participants in the experiment group received vibrotactile biofeedback from the system after finishing scaling (Feedback), while those who were in the control group received no feedback (Control).

Data analysis

The primary outcome measures were the mean values of $Back_x$ degree and $Back_y$ degree. The secondary outcome measure was upper trapezius muscle activity measured using electromyography (EMG). The primary and secondary outcome measures were recorded two times: after finishing scaling on the 1st molar (Pre-test) and finishing scaling on the 2nd molar (Post-test). The primary outcome measures were the angle in degree at 10th, 50th, and 90th percentile of $Back_x$ and $Back_y$ accurate to 0.01 degree. The secondary outcome measures were raw EMG signals processed with BioPAK™ Program software V 7.2 (BioResearch Associates Inc., RI, USA). Raw EMG data was transformed into frequency domain and band-pass filtered at a high-pass frequency of 10 Hz and a low-pass frequency of 500 Hz. Then, the data was inverse-transformed to time domain for further analysis. Accordingly, filtered signals were full-wave rectified and averaged across data collection period.Descriptive statistics were used to evaluate the effects of real-time personalized biofeedback system. Average, standard deviations and percentile were extracted as well as the percent change of post-test from pre-test. Personalized biofeedback effects (control vs. feedback group) were evaluated using the Paired t-test and were assumed to be significant at $p < 0.05$ (two-side). All analyses were conducted with the statistical package for the Social Science version 21.0 (SPSS, Chicago, IL).

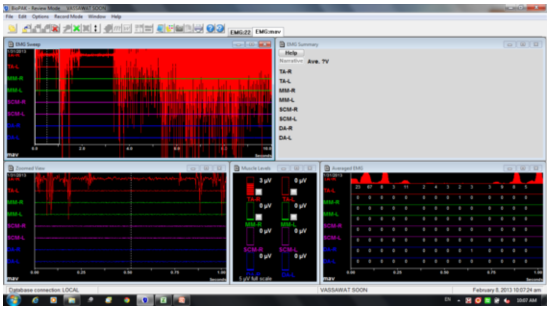
Results

Dental students that received feedback from the system had lower tilt angles at 10th, 50th, 90th percentile of $Back_x$ and $Back_y$, as well as muscular load which were statistically different ($p < 0.05$) from those who received no feedback from the system. A significant improvement of 3.62-8.47 degrees was seen for forward movements, and 6.12-8.88 degrees for sideways movements in the group that received feedback. A sample EMG that shows muscular load for the right trapezius from one participant doing dental procedure is shown in Figure 3. There was lower muscular load for the right trapezius while receiving vibrotactile biofeedback from the system (Figure 3b), as compared to receiving no feedback (Figure 3a).

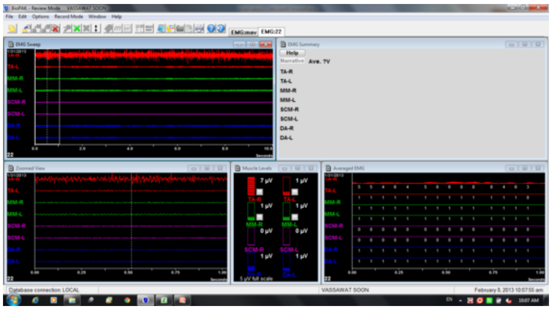
Discussion

In a previous study, a real-time system with assistive feedback for postural control in rehabilitation found that the system was suitable for clinical applications pertaining to postural control improvements.[20] The limitations were that custom-developed software might not effectively be applied to all patients. Another study applied a wearable real-time intelligent posture corrective system using vibrotactile feedback to improve ankle proprioception in wobble board training. A fuzzy inference system was used to determine the quality of postural control, based on inertial measurement units-acquired measurements of trunk and wobble board. The results observed an improvement in postural control with biofeedback intervention, demonstrating the success of the prototype built for improving postural control in rehabilitative and preventive applications.[21]

In our study besides posture position, the muscle activity was also assessed using EMG. During dental work there was higher load for the right trapezius in the control group, as compared to the feedback group. Our results are in line with the study on quantifying work load in neck, shoulders and wrists in female dentists.[22] It was found that dentists were exposed to high load on the trapezius muscles bilaterally, and steep, prolonged forward bending of the head.



(a)



(b)

Figure 3 - Relationships between muscular activity and maximal voluntary contraction (MVC) for right trapezius muscle of (a) control and (b) feedback from one participant. The upper-left window shows EMG sweep in 10 sec. of right trapezius muscle (read from TA-R electrode). The lower-left window is the zoomed view of EMG in 1 sec. The lower-middle window shows a single muscular activity level selected from the zoomed view. The lower-right window shows average EMG in 1 sec.

As hypothesized, the postural training using personalized biofeedback reduced muscle activity significantly. Trapezius muscle activity has been studied previously in dental work research due to the discomfort that is experienced in the neck/shoulder region.[22,23] The magnitude of EMG signals of the Trapezius muscles while working on the dental procedure were compared between sitting in the conventional chair and General Chair (Ergonomically Designed Chair EDC;) designed by strong support over the arms and trunk.[24] The results showed that the chairs are designed specifically to reduce activity of the muscles significantly and MVE% is close to the average value that is derived from data received participants' using personalized biofeedback in this study.

A study on biofeedback with muscle activity by Palmerud et al. [25] examined with electromyography in abducted arm positions. By using feedback techniques, they found that the subjects could reduce EMG activity voluntarily by 56% in the trapezius muscle while keeping different static postures. When compared with this study, the values of the EMG activity from a feedback group decrease by 53.15%. Thus, while you are working in the appropriate position, the function of the muscle decreases.

Many research experiments have been introduced using biofeedback information. Biofeedback systems have become a prominent component in motor training and rehabilitation. Alahakone et al. [20] found that instantaneous feedback provided via vibration stimulus can reduce postural sway based on trunk tilt measurements. Hence, the system's pertinence to comparable approaches employed in sports training and rehabilitation is apparent. Correspondingly, vibrotactile biofeedback improves gait in patients with unilateral vestibular loss. Results showed an immediate improvement in postural stability (reduction of lateral center of mass displacement, trunk tilt and medial-lateral step width), that was significantly larger than effects of practice alone.[26] In addition to evaluate the effectiveness of an audiobiofeedback system for improving balance in patients with bilateral vestibular loss. Audiobiofeedback improved stance stability of participants with bilateral vestibular loss by increasing the amount of postural corrections.[27]

To our knowledge, this is the first intervention trial using a personalized biofeedback system for training posture in dental students. The present study aimed to explore if this training method is feasible for dental students. Future studies should include a larger sample of dental students and dentists, as well as other occupations (e.g., surgeons, computer users, or drivers). Training with the personalized biofeedback system teaches participants new strategies of movement that could be applied to real-life situations. In this sense, the personalized biofeedback system may have an advantage over other technologies used by dentists, by enhancing motor learning through feedback on knowledge of performance, and knowledge of results. Further studies are needed to look at the possibility of using a personalized biofeedback system for daily training.

Conclusions

The results presented here demonstrate that the personalized biofeedback system for posture training in dental students is feasible, and associated with quantitative improvements of dental posture. This may be viewed as a promising first step to implement posture training strategies to minimize work-related musculoskeletal disorders in dentists and other healthcare workers.

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