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The biomechanical demands of manual scaling on the shoulders & neck of dental hygienists

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ABSTRACT
The purpose of this study was to evaluate the postural and muscular demands placed on the shoulders and neck of dental hygienists when performing a simulated manual scaling task. Nineteen healthy female dental hygienists performed 30-min of simulated manual scaling on a manikin head in a laboratory setting. Surface electromyography was used to monitor muscle activity from several neck and shoulder muscles, and neck and arm elevation kinematics were evaluated using motion capture. The simulated scaling task resulted in a large range of neck and arm elevation angles and excessive low-level muscular demands in the neck extensor and scapular stabilising muscles. The physical demands varied depending on the working position of the hygienists relative to the manikin head. These findings are valuable in guiding future ergonomics interventions aimed at reducing the physical exposures of dental hygiene work.

Practitioner Summary: Given that this study evaluates the physical demands of manual scaling, a procedure that is fundamental to dental hygiene work, the findings are valuable to identify ergonomics interventions to reduce the prevalence of work-related injuries, disability and the potential for early retirement among this occupational group.

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1. Introduction

Despite recent advancements in dental tool design and ergonomics education, work-related musculoskeletal disorders (WMSDs) remain highly prevalent among dental professionals (Hayes, Cockrell, and Smith 2009). Dental hygienists have typically reported a greater prevalence of WMSDs compared to other dental professionals (e.g. dentists and dental assistants), and are thought to have a greater risk for developing upper extremity and back pain (Morse, Bruneau, and Dussetschleger 2010; Rice, Nindl, and Pentikis 1996). The physically demanding nature of dental hygiene work is manifested in the particularly high prevalence of WMSDs in the neck (39–84%) and shoulder (39–76%) regions (Anton et al. 2002; Booyens, van Wyk, and Postma 2009; Hayes, Cockrell, and Smith 2009; Liss et al. 1995; Michalak-Turcotte 2000; Morse, Bruneau, and Dussetschleger 2010).

The high prevalence of WMSDs is considered to be a leading contributor to the early retirement of dental hygienists, particularly when coupled with the challenging psychosocial demands experienced in the profession (Burke and Main 1997; Leggat, Kedjarune, and Smith 2007). Although the specific dental procedures performed by dentists and dental hygienists are substantially different, both professions undergo similar biomechanical demands over the course of a day (Åkesson, Balogh, and Hansson 2012; Marklin and Cherney 2005). Both professions require the worker to maintain similar awkward static postures while performing precise manual tasks and exerting repetitive low-level forces (Ettinger et al. 2012; Rempel, Villaneuva, and Dong 2009). Awkward static postures, precision work and repetitive low-level force exertion have been identified as risk factors for the development of WMSDs (Bernard 1997; Ettinger et al. 2012; Hagberg and Hagberg 1989). For instance, in a detailed evaluation of the upper extremity physical demands experienced during dental hygiene work, the most likely physical exposures for developing neck and shoulder WMSDs are excessive neck flexion, constrained working postures and excessive static and peak loading of the upper trapezius (UT) and forearm extensor muscles, respectively (Åkesson, Balogh, and Hansson 2012). Previous research has partially attributed the poor

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postures typically observed during dental hygiene work to the constrained physical nature of the work coupled with the need to maintain visual contact with the client's oral cavity at all times (Haslegrave 1994; Sunnel and Rucker 2004).

Manual scaling of the teeth, or debridement of plaque and calculus from the surface of the tooth, has commonly been identified as the most demanding task performed by dental hygienists, and is cited as the task with the highest risk for developing WMSDs in the upper limbs and neck (Åkesson, Balogh, and Hansson 2012; Hayes, Smith, and Cockrell 2010; Rempel, Villaneuva, and Dong 2009; Ylipaa, Arnetz, and Preber 1999). In addition to its high demand, several studies and reviews have shown that the majority of time spent by dental hygienists during a typical appointment involves some form of scaling (Anton et al. 2002; Bramson, Smith, and Romagnoli 1998).

To adequately scale each surface of every tooth, the dental hygienists have to adjust their working position and pelvic orientation relative to the client to ensure appropriate vision and manual access to the client's oral cavity (Liss et al. 1995). The working position has typically been quantified by dividing the various positions into segments of a clock, with 12 o'clock referring to the top of the client's head, 9 o'clock referring to the client's right side and 6 o'clock referring to the client's feet (Howarth et al. 2015; Nield-Gehrig 2008). In a study evaluating the physical demands of dental hygiene work on the lower back region, it was noted that the location of the dental hygienist (i.e. their 'clock position') during manual scaling influenced the dental hygienist's pelvic orientation relative to the client, seat-pressure distribution, spine posture and muscular loading (Howarth et al. 2015). Working from the 8 o'clock position was more demanding on the low back than other clock positions; however, it is unknown whether the same is true for the neck and shoulders.

Therefore, the purpose of the current study was to evaluate: (1) the overall biomechanical demands on the neck and shoulders during a 30-min scaling task, and (2) the individual muscular and postural differences when working at different clock positions. Developing an understanding of the biomechanical demands at the different clock positions can help inform future ergonomic interventions and potentially reduce the high prevalence of injuries afflicting this professional population.

2. Methods

2.1. Participants

The participants consisted of 19 female registered dental hygienists (age = 30.6 ± 5.5 years, height = 1.66 ± 0.09 m, mass = 63.1 ± 15.2 kg), who had been in practice for an average of 4.9 ± 3.7 years. None of the participants reported any current lower back, neck or shoulder pain prior to the start of data collection. Data from two participants were excluded from further analysis due to instrumentation issues that arose during data collection. Of the remaining 17 participants, two were left-hand dominant, and 15 were right-hand dominant, but all hygienists typically worked from the right side in their dental clinics. This study was reviewed and approved by the Institution's Research Ethics Board, and all participants signed an informed consent document prior to beginning instrumentation set-up.

2.2. Instrumentation & data acquisition

2.2.1. Electromyography

Surface electromyography (sEMG) was recorded bilaterally from six muscles of the shoulder girdle and neck, including: cervical erector spinae (CES) and UT for the neck, and pectoralis major (PM), anterior deltoid (AD), posterior deltoid (PD) and lower trapezius (LT) for the shoulder. UT can also elevate the scapula, but for the purposes of this paper, it was considered a 'neck' muscle. sEMG was also collected from the thoracic and lumbar erector spinae, but these data were presented elsewhere (Howarth et al. 2015).

All sEMG signals were recorded using parallel bar electrodes separated by a fixed distance of 10 mm (CMRR = 92 dB at 60 Hz, Input impedance = 10^6 GΩs)(DE-2.1, Delsys Inc., Boston, MA). Analog sEMG signals were processed through a differential amplifier (range = ±5 V, bandpass filter 20–450 Hz) (Bagnoli-16, Delsys Inc., Boston, MA) and were then digitally sampled at a rate of 2048 Hz by a 16-bit analog-to-digital conversion system (ODAUIII, Northen Digital Inc., Waterloo, ON, Canada).

2.2.2. Kinematics

Three-dimensional kinematic data were obtained using two banks of optoelectronic cameras (3 cameras in each bank, for a total of 6) at a sampling rate of 32 Hz (Optotrak Certus, Northern Digital Inc., Waterloo, ON, Canada). Nine sets of three infrared light emitting diodes (IREDs) were affixed to plastic rigid bodies that were secured to the head, neck, upper arms, thorax and pelvis of each participant (Figure 1). Two rigid bodies were affixed to a headband and placed on the posterior and right lateral aspects (above the ear) of the cranium. Neck and thorax rigid bodies were centred on the spinous processes of C7 & T12, respectively. Four rigid bodies for the right and left arms were fixed to straps and secured over the posterior-lateral aspects of the upper arms, at approximately the midpoint of each segment. Several anatomical landmarks of the dental hygienist's upper arms, thorax and head were also digitised and virtually tracked relative to the IRED rigid bodies throughout the experiment.

Figure 1. A lateral view of a dental hygienist performing the simulated manual scaling task.
Note: The dental hygienist is shown working at approximately the 11 o'clock position.

An additional rigid body was placed on the back of the operator's chair and locations identifying the front and back edges of the seat pan were digitised. Static points were also digitised on a manikin head (M-1R-DA-8, Columbia Dentoform Corp., Long Island, NY, USA) and foam torso that were used to simulate a client. Kinematic data from the manikin's head and torso allowed for continuous monitoring of the dental hygienist's working position (i.e. clock position) and orientation with respect to the simulated client (manikin) throughout the experiment.

2.3. Experimental procedures & protocol

Prior to initiating the experimental protocol, the dental hygienists were familiarised with the experimental set-up and equipment. The dental hygienists were asked to adjust the height of their operator stool and dental hygiene client chair (Spirit 3300, Pelton & Crane, Charlotte, NC, USA) to a comfortable working level before the experiment began. These initial settings remained constant throughout the protocol, as the final location of the manikin was digitised relative to the global coordinate system of the lab.

As this was a laboratory-based study, a set of typodont teeth mounted within a manikin head were used in lieu of a human client. The manikin head was secured to the headrest of the client chair and remained stationary throughout the experimental protocol. An adult sized foam torso was also placed on the chair to make the set-up as realistic as possible. This was important since during pilot testing without the foam torso in the client chair, dental hygienists were noted to position their right arm in the space that would normally be occupied by the client's torso. Finally, a backless dental hygiene operator stool was used to allow access for recording the optoelectronic kinematic data. After shaving and cleaning the skin, sEMG electrodes were placed bilaterally on the aforementioned muscles. Next, a series of maximum voluntary contractions (MVCs) were performed to elicit maximum voluntary excitations (MVEs) for each muscle. One MVC was performed for each muscle against manual resistance applied by an investigator. Further detail on the MVC protocol for each muscle can be found in Howarth et al. (2015). The sEMG set-up was completed with a five second resting baseline trial, in which participants lied quietly on a bed with all muscles relaxed to determine the sEMG amplitude that was not associated with myoelectric activity, which was subtracted during post-processing from the sEMG data obtained during all other trials.

After application of the kinematic instrumentation, baseline active neck range of motion (ROM) measures were recorded in flexion/extension, lateral bending and axial rotation for each dental hygienist. All shoulder kinematics were expressed in absolute rather than relative terms (i.e. degrees vs. %ROM).

Each dental hygienist completed a simulated dental hygiene task that consisted of 30-min of manual scaling. All dental hygienists performed the task while seated on the operator stool using their choice of a variety of scaling instruments that were provided (D-Sharp Dental Instruments, Stoney Creek, ON, Canada). The instrument tray was placed to the right of the dental hygienist, but its specific location could be adjusted throughout the course of the experiment. The scaling task involved removing gold coloured nail polish, which was applied by the experimenters to the typodont teeth to simulate plaque. The use of nail polish to simulate plaque has been used in previous studies (Dong et al. 2005, 2007). The removing of plaque is typically conducted with the dominant task hand, while a mirror is held in the non-dominant hand to help retract the lips and tongue, and to visualise the scaling. The dental hygienists were free to complete the task in the manner of their choosing, but were requested to scale all quadrants of the mouth within the allotted duration of 30-min. The dental hygienists were free to switch instruments whenever needed, and could also adjust the angle and placement

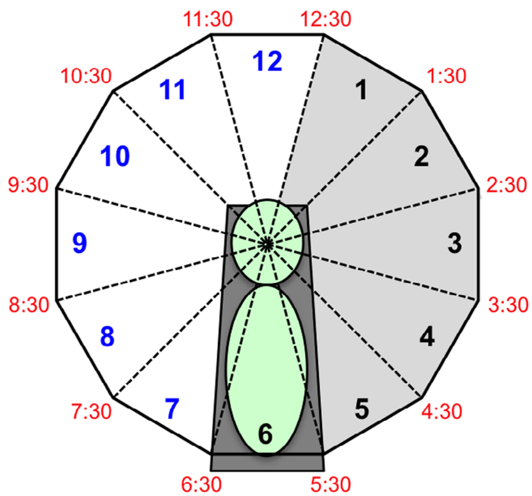

Figure 2. Schematic of the working/clock positions, relative to the client lying supine in the patient chair (overhead view looking down on client).

Notes: Bolded numbers within each triangle indicates the clock position ranges. The actual clock numbers shown in un-bolded red text delineate the borders of each range. Clock positions from which the dental hygienists were not permitted to work are shaded in grey.

of their overhead lamp. Due to camera viewing angle limitations, the dental hygienists were unable to work on the left side of the manikin's head, and were instructed not to go past the 12 o'clock position. All left-handed dental hygienists were asked to work from the same side of the client as the right-handed dental hygienists (i.e. 8 o'clock to 12 o'clock) (Figure 2).

2.4. Data analysis

Visual3D analysis software (C-Motion Inc., Germantown, MD, USA) was used to process all sEMG and kinematic data. Raw sEMG data from all trials were full-wave rectified and low-pass filtered using a 2nd order Butterworth filter with a cut-off frequency of 2.5 Hz to create linear envelopes (Brereton and McGill 1998; Howarth et al. 2015; Winter 1990). Minimum values from the linear envelopes for each sEMG channel during the resting trial were subtracted from the linear envelopes of sEMG data obtained during all MVC and simulated scaling trials. Finally, adjusted linear envelopes of sEMG data from the simulated scaling task were normalised to the respective MVEs obtained during the MVC trials and expressed as a percentage of maximum activation.

Kinematic data were low-pass filtered using a dual pass 2nd order Butterworth filter with a cut-off frequency of 3 Hz. Cubic spline interpolations were used to fill missing kinematic data over a maximum window of 7 frames (Howarth and Callaghan 2010). As the degree of torso flexion was shown to be variable throughout the scaling protocol (Howarth et al. 2015), upper arm posture was simply expressed as the elevation angle of the humerus with respect to gravity. Relative angular orientations between the dental hygienist's head and torso were used to determine neck posture throughout the experimental protocol. Head deviations in flexion/extension, left/right lateral bending and left/right axial twist, relative to the top of the thorax, were expressed as a percentage of the maximum ROM in those three axes. Anterior head carriage was also quantified as the amount of the head's forward translation with respect to the thorax.

All kinematic and sEMG time-series data were analysed using amplitude probability distribution functions (APDFs), to determine the static (10th percentile, $p = 0.1$), median (50th percentile, $p = 0.5$) and peak (90th percentile, $p = 0.9$) levels of exposure across the entire 30-min task (Jonsson 1982). For bi-polar kinematic measures (i.e. neck kinematics), 10th percentile values corresponded to peak angular deviations in left lateral bend and right axial twist, and 90th percentile values corresponded to peak angular deviations in right lateral bend and left axial twist. A novel variable (%MVE_{normJ}) was created to express the normalised muscle activity with respect to Jonsson's proposed static, median and peak maximum activation limits for an 8-h day (i.e. 2% for static, 10% for median and 50% for peak) (Jonsson 1982). Values above one indicated that the limit was exceeded.

Kinematic and sEMG data were also stratified by clock position to determine the median neck deviations (%ROM), anterior head carriage (m), arm elevations (degrees) and muscle activations (%MVE) within each hour between 8 and 12 o'clock. Left arm elevation data could not be recorded at the 12 o'clock position due to technical limitations with the motion capture system. Clock position was defined using the angle created between: (1) a line connecting the centre of the pelvis to the centre of the manikin's head and (2) a projection of the lateral axis extending through the tragi (ears) of the manikin head. Using this convention, angular ranges were defined that corresponded to a particular clock position (Howarth et al. 2015).

2.5. Statistical analysis

As the dental hygienists were not experimentally forced into each one of the clock positions, unequal sample sizes were observed at each of the locations. For this reason, the 12 o'clock level was removed from the clock position independent variable in all analyses of variance (ANOVAs), as only three participants were observed to spend minimal time in this range. For the median sEMG and kinematic variables stratified by clock position, separate two-factor (4 clock positions, 2 sides) between-subject ANOVAs (SPSS Version 21, SPSS Corp., Chicago, IL, USA) were conducted for each of the neck and shoulder muscles, as well as arm elevation angles. All kinematic dependent variables, pertaining to neck posture, were analysed by separate one-factor (clock position) between-subject ANOVAs. For any independent variables involved in a significant interaction, *post hoc* tests were conducted with t-tests to compare the means between clock positions for each side. For independent variables involved in only a main effect, *post hoc* tests were conducted with t-tests to compare between means from each level of that independent variable. In each case, Holm's adjustments were applied to account for multiple comparisons. All statistical tests were conducted with significance set at $p < 0.05$.

We also computed descriptive statistics (e.g. mean, standard deviation and coefficient of variation), for the static, median and peak values obtained from the APDFs of the entire 30-min task.

3. Results

3.1. Muscle activation

For median neck muscle activations, a significant interaction was found between clock position and side for UT ($F = 4.31$, $p < 0.007$, $\omega^2 = 0.085$). The only significant difference between clock positions was a 3.1% MVE increase between the 8 and 10 o'clock positions for the left side, and a 1.5% MVE decrease between the 9 and 11 o'clock position for the right side. There were no significant main effects or interactions found for CES (Table 1).

For the shoulder muscles, there was a significant interaction between clock and side for PD ($F = 4.94$, $p < 0.004$, $\omega^2 = 0.085$). There were also significant main effects of clock ($F = 2.89$, $p < 0.04$, $\omega^2 = 0.050$) and side ($F = 3.95$, $p < 0.05$, $\omega^2 = 0.026$) for PM, and a main effect of side for LT ($F = 11.79$, $p < 0.002$, $\omega^2 = 0.122$). Right PD activity progressively decreased from 8 to 9 (5.8% MVE) to 10 (8.0% MVE) to 11 o'clock (8.1% MVE). The only significant main effect after adjustment was found between sides for PM, with PM activity being greater for the left side (4.5 ± 1.9% MVE) compared to the right side (3.3 ± 2.3% MVE).

When all clock positions were combined across the entire task, both CES and UT exhibited static muscle activities above the recommended limits (Figure 3). The largest of these activations was a $\%MVE_{normJ}$ of 2.79 for right CES and 2.73 for left CES. The static levels of right and left UT were also near the limit (1.00 and 1.01% MVE_{normJ}, respectively). The only muscle to exceed the median recommended activity level was right CES (1.05% MVE_{normJ}), with left CES nearly exceeding the limit as well (0.961% MVE_{normJ}). The only shoulder muscle with a $\%MVE_{normJ}$ above 1.0 was right LT (1.39% MVE_{normJ}), which exceeded the static limit.

Table 1. All median sEMG activations, stratified by level of ANOVA result (i.e. 2-way interaction between clock and side, side main effect and clock main effect).

Level of ANOVA result	Muscle	Side	Clock	Mean (%MVE)	St.Dev	*n*	Sig.	Muscle	Side	Clock	Mean (%MVE)	St.Dev	*n*	Sig.
2-way Interaction: (Clock x Side)	*UT (neck)*	Left	8	3.5	2.8	13	¥	*PD (shld)*	Left	8	0.9	0.7	13	
			9	5.5	4.1	17				9	2.2	2.1	17	
			10	6.6	5.2	16	¥			10	2.6	2.9	16	
			11	5.5	2.4	10				11	1.5	1.2	10	
			12	*5.3*	*1.1*	*3*				*12*	*1.6*	*1.3*	*3*	
		Right	8	7.3	3.4	12			Right	8	10.0	17.1	12	¥
			9	6.1	2.9	16	£			9	4.2	3.1	16	£
			10	4.6	2.9	15				10	2.0	1.4	15	£
			11	4.6	3.2	10	£			11	1.9	1.0	10	¥
			12	*6.1*	*2.9*	*3*				*12*	*3.4*	*1.6*	*3*	
Main Effect: (Side)	*PM (shld)*	Left		4.5	1.9	12	ψ	*LT (shld)*	Left		4.3	4.2	10	
		Right		3.3	2.3	16	ψ		Right		6.2	5.1	10	
Main Effect: (Clock)	*PM (shld)*		8	4.5	1.9	12	δ,φ	*AD (shld)*		8	4.7	4.4	13	
			9	3.3	2.3	16				9	2.6	1.7	17	
			10	2.4	1.7	15	δ			10	2.4	2.3	16	
			11	2.7	1.3	10	φ			11	1.6	1.6	10	
			12	*2.6*	*1.3*	*3*				*12*	*1.1*	*0.9*	*3*	

Notes: Significant *post hoc* differences between clock position and side means are indicated by two rows sharing a common symbol (p<0.05). Two-way interaction *post hoc* comparisons were made for the clock positions within each side. For example, 8 and 10 o'clock means were significantly different for the left UT. Descriptive statics for the 12 o'clock positions are shown (in italics), but these data were not included in the ANOVAs due to their relatively small sample sizes.

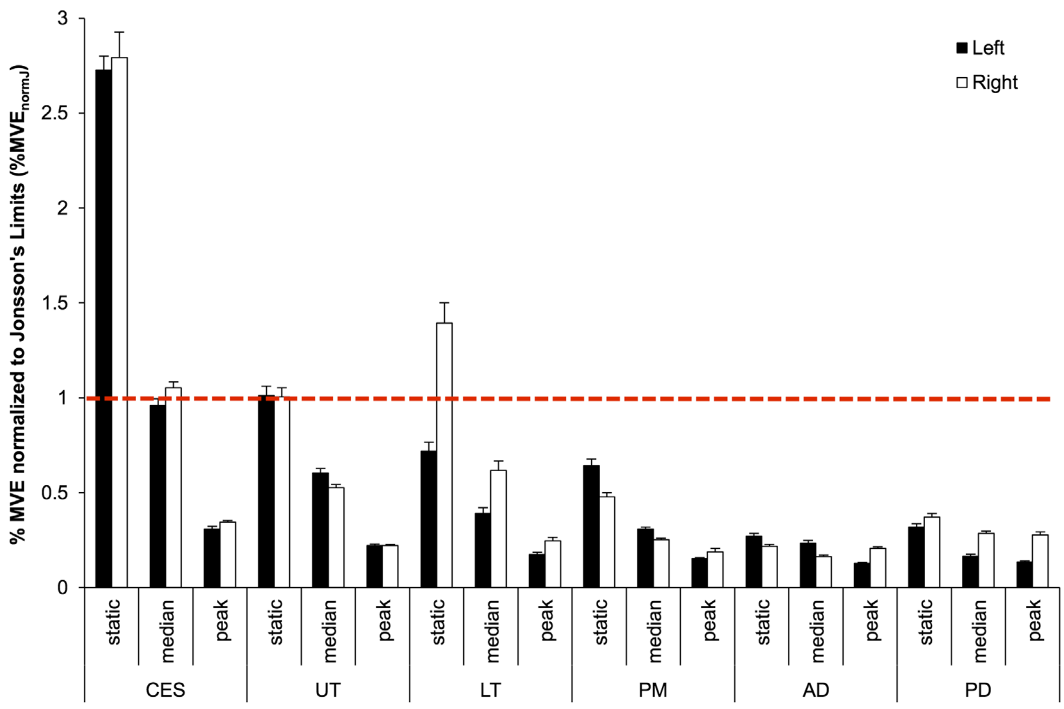

Figure 3. Static (10th), median (50th) and peak (90th percentile) sEMG levels of each muscle expressed relative to the respective recommended muscle activity thresholds of 2, 10 and 50% MVE, respectively, from Jonsson (1982).

Notes: Any values greater than 1.0% MVE$_{normJ}$, indicated by the dashed red line, represent muscles that have exceeded their recommended static, median or peak muscle activation for the overall task. Error bars indicate standard error.

Table 2. The mean and standard deviation of each subject's median neck flexion, neck lateral bend and anterior head carriage, separated by clock position. Negative lateral bend values represent a deviation to the left whereas positive values represent a deviation to the right.

	Neck Flexion (%ROM)					Neck Lateral Bend (%ROM)					Anterior Head Carriage (m)				
Clock Position	8	9	10	11	12	8	9	10	11	12	8	9	10	11	12
Mean	37.7	50.7	49.5	46.2	54.6	3.6	1.9	5.1	9.9	−17.4	0.11	0.11	0.12	0.12	0.13
St.Dev	25.0	20.2	24.7	20.2	8.4	27.4	17.0	27.0	25.8	21.2	0.03	0.03	0.02	0.03	0.03
n	11	15	14	9	3	12	16	15	9	3	13	17	16	10	3

3.2. Kinematics

There were no significant main effects of clock position for neck flexion, lateral bend or anterior head carriage (Table 2), but there was a main effect for the 50th percentile of neck axial twist ($F = 5.93$, $p < 0.002$, $\omega^2 = 0.221$) (Figure 4). Axial twist at the 8 o'clock position was significantly deviated to the left when compared to the 9, 10 and 11 o'clock positions ($p < 0.005$).

A significant interaction (clock, side) was found for arm elevation angle ($F = 8.49$, $p < 0.001$, $\omega^2 = 0.152$). Post hoc testing revealed no significant differences between clock positions within the left arm, but the right arm was significantly more elevated at 8 and 9 o'clock when compared to 10 and 11 o'clock (Figure 5). The largest discrepancy in right arm elevation angle was a 23° difference between 10 and 8 o'clock.

Over the entire task, a large range of postures was observed for both the neck and shoulder (Figure 6). Differences between static and peak APDF values spanned 77% of the overall lateral bend ROM, and 41% of the overall ROM for both neck flexion and axial twist. Neck flexion angle had a coefficient of variation (CV) of 33.2% but greater than 90% of the time was spent above 24% of the flexion ROM.

4. Discussion

The main findings of this study were that the simulated manual scaling task resulted in excessive demands for both the neck and shoulders of dental hygienists. Most notably, the constant neck flexion and arm elevation angle resulted in excessive tonic activation of the neck extensor (CES & UT) and scapular stabilizer (LT) muscles. The highest demands were most often observed at the 8 o'clock working position, particularly for neck axial twist and right arm elevation.

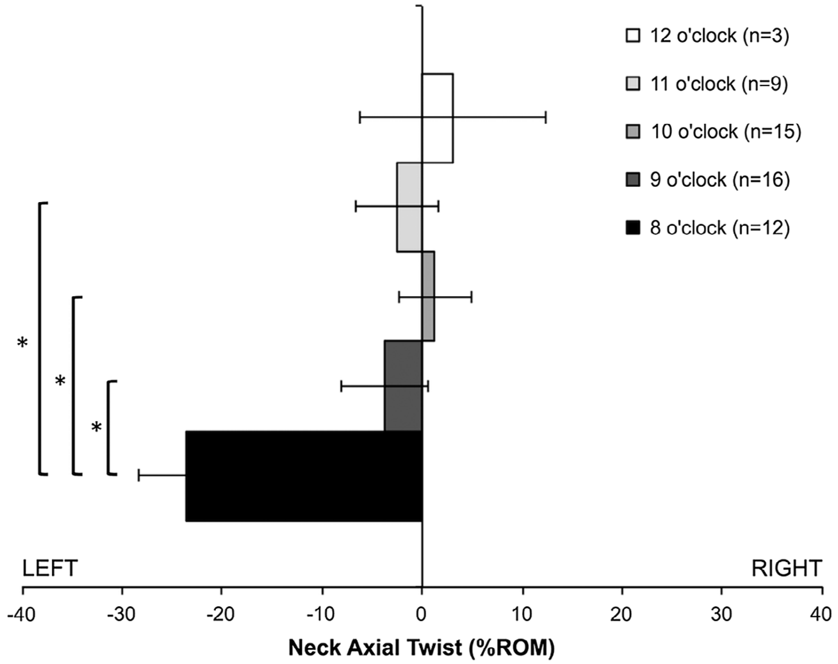

Figure 4. Neck axial twist (%ROM) pooled within clock positions (n for each group shown in the figure legend).
Notes: Error bars indicate standard error, and brackets with asterisks indicate significant differences between means after Holm's adjustments for multiple comparisons. Data from the 12 o'clock position were not included in the ANOVAs due to their relatively small sample sizes.

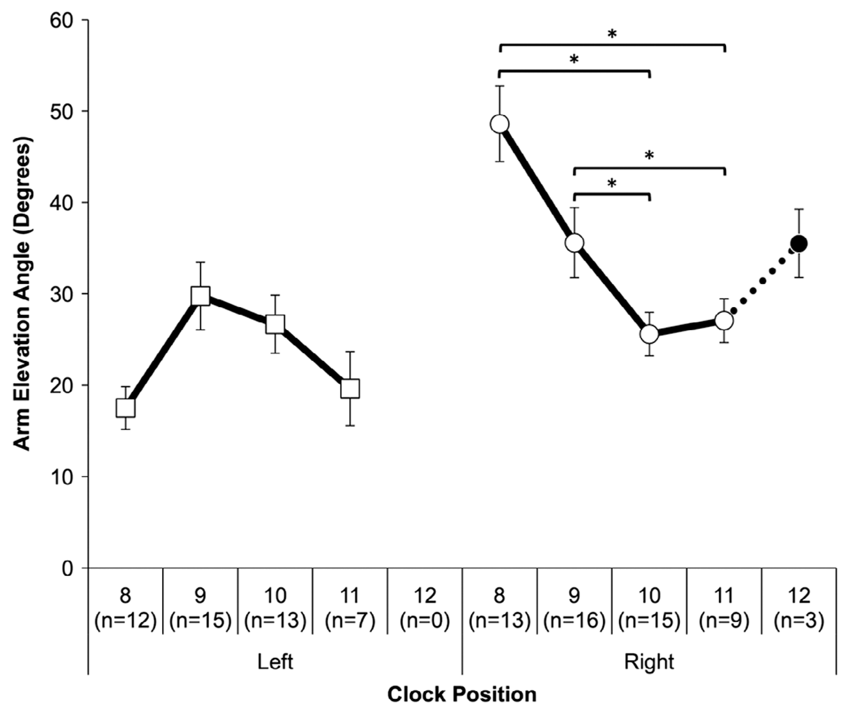

Figure 5. Median left and right arm elevation angle, pooled within clock positions.
Notes: The *n* of each mean is shown in the horizontal axis. Standard error bars are shown and brackets with asterisks indicate significant differences between means after Holm's adjustments for multiple comparisons. Right arm elevation at 12 o'clock was not included in the ANOVA, but the mean and standard error are plotted for reference. Arm elevation at 12 o'clock was not recorded for the left arm due to visualisation issues between the kinematic markers and the cameras.

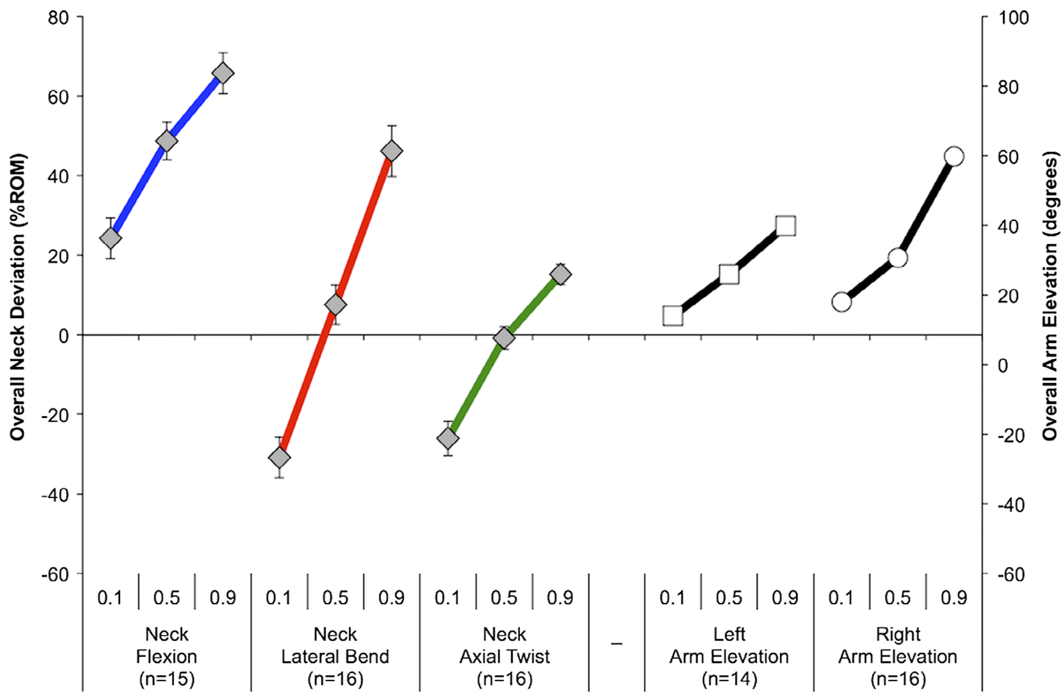

Figure 6. The 0.1, 0.5 and 0.9 APDF probability values for overall neck flexion, lateral bend and axial twist, and for left & right arm elevation.

Notes: Neck deviations are normalised to %ROM (left axis), and negative lateral bend and axial twist values represent deviations to the left. Overall arm elevation is plotted in degrees (right axis). Standard deviation bars are shown and the n of each mean is shown in the horizontal axis.

4.1. Physical demands on the neck

The dental hygienists were found to spend greater than 90% of their time with at least 13.1° of neck flexion (or 24% ROM) and 0.133 m of anterior head carriage. This led to levels of static (10th percentile) and median (50th percentile) muscle activation of the CES that exceeded the recommended limits (Jonsson 1982). Neck flexion, anterior head carriage and CES muscle activity also did not appear to be dependent on clock position. These data suggest that there was very little rest provided to the neck extensor muscles throughout the scaling task, which was reflected in the high static muscular activations. With a 10th to 90th percentile range of 24.3% to 65.7% ROM (or 13.1° to 34.3°), the neck flexion values observed in this study were comparable to those seen previously in the literature (Åkesson, Balogh, and Hansson 2012; Finsen 1999; Lindegård, Gustafsson, and Hansson 2012; Marklin and Cherney 2005). Based on these combined findings, the forward flexed neck posture observed in dental hygienists is problematic, as prolonged flexion of the cervical spine is a well-known risk factor for developing neck pain (Winkel and Westgaard 1992).

A static muscle activity of 5.45% and 5.58% MVE for left and right CES, respectively, exceeded both the 8-h (2% MVE) and 1-h (5% MVE) recommended occupational exposures, as suggested by Jonsson (1982). Furthermore, right CES also exceeded the 10% MVE median limit for an 8-h day. The static activity levels of UT were also near the suggested limits, which may be an indication of continuous shoulder shrugging or providing a neck extensor moment. Low level, continuous muscular loading can lead to the accumulation of fatigue in the neck extensor muscles and eventual breakdown of the tissues if sufficient recovery time is not provided (Armstrong et al. 1993; Larsson, Søgaard, and Rosendal 2007).

Our observed neck muscle activity was also in agreement with several previous investigations. In previous studies, upper trapezius was often observed to be the most heavily recruited muscle during dental work, particularly at the static level (Åkesson, Balogh, and Hansson 2012; Milerad et al. 1999). Finsen (1999) postulated that neck sEMG might underestimate the mechanical demand on the neck extensor structures during dental hygiene work, as large physical demands are also placed on the passive structures of the neck when constantly in a flexed posture. Therefore, the risk to the neck may actually be higher than the already excessive CES and UT static activations observed in our study, and others.

Among the kinematic variables evaluated, only neck axial twist was influenced by clock position. Neck axial twist remained close to neutral from the 9 to 12 o'clock positions, but was significantly deviated to the left at the 8 o'clock position. Neck twisting to the left, in combination with neck flexion, is a common behaviour in the dental profession (Smith et al. 2002; Valachi and Valachi 2003). The neck twisting deviation observed in our study occurred concomitantly with a significant difference in left UT activation vs. the right at the 8'clock position. Leftward neck axial twist observed at 8 o'clock is likely related to the right twisted lumbar spine posture and leftward orientation of the dental hygienist's pelvis (Howarth et al. 2015). In this study, it was subjectively noted during data collection that dental hygienists working from this clock position were often not able to place their legs under the dental chair, which forced them to compensate by rotating their pelvis and legs to the left. This led to an increased sitting pressure distribution to the right, and subsequent twisting of the spine to the right (Howarth et al. 2015).

4.2. Physical demands on the shoulder

A large range of arm elevations was observed across the 30-min scaling task. The CV in right arm elevation was 53.1%, compared to 38.9% for the left arm, meaning that there was more overall postural variability present with the right arm, which is consistent with previous studies (Åkesson, Balogh, and Hansson 2012). The right arm had a greater peak elevation compared to the left arm (59.7° vs. 39.8°). Aside from any task differences attributable to scaling, rather than manipulating a mirror with the left hand (for most participants), the right hand was also used to reach for new scaling instruments and to adjust the overhead lamp periodically. This is perhaps why the largest difference between right and left arm elevation was found at the peak (90th percentile) probability level.

Very few studies have specifically evaluated arm elevation during dental hygiene work. Marklin and Cherney (2005) found that dental hygienists spent more than half of their time with their arms abducted above 30°. Åkesson, Balogh, and Hansson (2012) evaluated arm postures specific to a scaling task and found a 99th percentile resultant peak arm elevation of 77° for the right arm and 66° for the left arm, compared to our 90th percentile arm elevations of 59.7° (right) and 39.8° (left). An important distinction between Åkesson, Balogh, and Hansson (2012) and our study is that we calculated arm elevation angle with respect to gravity rather than the torso. Since gravity provides the primary external load acting on the arm during dental hygiene, we felt that reporting arm elevation with respect to gravity provided a more appropriate surrogate representation for the moment demands experienced by the shoulder complex. For example, if the arm is flexed forward by 30° relative to the trunk, but is parallel with gravity (i.e. vertically oriented in the global lab coordinate system), the physical demand from the shoulder muscles to hold the arm in this position is minimal.

The increased arm elevation on the right side also manifested in higher activity from the right shoulder muscles. One of the most noticeable discrepancies was for the right LT, which had a static $\%MVE_{normJ}$ of 1.39 (i.e. 39% above the limit). Constant low-level muscle activity has been suggested as a possible mechanism for pathological anterior tilting of the scapula, which can have an influence on the development of subacromial impingement syndrome (Ettinger et al. 2012). As the lower fibres of the trapezius muscle are primarily involved in scapular stabilisation, constant low-level muscle activation can have adverse short- and long-term effects on the development of pain and injury in the shoulder.

When broken down by clock position, the 8 and 9 o'clock dental hygienist positions required the most right arm elevation. This is an important finding, as more than half (56.1%) of the 30-min scaling task was spent within these two clock positions (Howarth et al. 2015). In particular, the arm elevations observed at 8 and 9 o'clock were significantly higher than those observed at the 10 and 11 o'clock positions, as these latter two positions allowed for the dental hygienist to be more neutrally oriented and closer to the manikin's head. Working in the 10 and 11 o'clock positions resulted in the least amount of lumbar spine twisting, which perhaps explains why we observed similar right and left arm elevation angles at these clock positions. Howarth et al. (2015) also postulated that the dental hygienists altered their sitting posture at the 8 o'clock position as a compensatory strategy to reduce the physical demands on the upper extremities. Results from the current investigation do not support that assertion, as the highest amount of neck twisting, arm elevation and muscular loading were also observed at the 8 o'clock location.

Increased right arm elevations at 8 and 9 o'clock were also consistent with elevated PD activation in these positions. In particular, right PD activation was found to be much higher at 8 o'clock compared to 11 o'clock. Activity of the PD is often higher when the abducted arm is required to pull away from the midline of the body into hyperextension (i.e. elbow behind the torso's coronal plane). This type of shoulder movement would be necessary for the primary scaling hand, especially when the arm is elevated in the 8 and 9 o'clock positions, and this may explain the higher activity of the right PD relative to the other clock positions.

4.3. Assumptions and limitations

As this study was conducted in a laboratory setting, there were several assumptions and limitations that should be addressed. Probably the most significant assumption was that manual scaling on a manikin head would be an appropriate surrogate for manual scaling on actual human clients. Using a manikin head to assess the physical demands of dental hygiene work is an approach that has been used previously (i.e. Dong et al. 2005, 2007). Anecdotally, each dental hygienist stated that they were satisfied with the realism of the simulated task and thought that the manikin adequately represented an actual client. One disadvantage of this approach is that the manikin head was stationary and could not be rotated like a healthy client's head in a real appointment. Also, while the left-handed participants were asked to work in a right-handed position, they reported that this did not feel awkward, as they were accustomed to working within a right-handed dental hygiene set-up given that most dental operatories are set up in this way.

Although manual scaling is considered to be the most demanding and prominent of all the tasks performed by dental hygienists (Åkesson, Balogh, and Hansson 2012; Hayes, Smith, and Cockrell 2010; Rempel, Villaneuva, and Dong 2009; Ylipaa, Arnetz, and Preber 1999), it only represents one of the many tasks that they perform during the course of a workday. Furthermore, although the use of mechanised ultrasonic scaling instruments has become more prevalent in dental hygiene practice, we were unable to evaluate this scaling approach due to methodological constraints. Previous work has found that this mechanised scaling approach only reduces forearm extensor muscular loading by a minimal amount with no reduction in upper trapezius loading (Åkesson, Balogh, and Hansson 2012), so it is not likely that using ultrasonic instruments would have shown any differences from the manual scaling method in our study. In addition, the dental hygienists reported that they still conduct manual scaling for a considerable amount of time during the client appointments.

4.4. Conclusions & overall recommendations

Based on the findings from this study, working at the 8 o'clock position appears to be the most physically demanding for the neck and shoulders of dental hygienists. A similar finding was also noted for the lower back region in a previous related study (Howarth et al. 2015). The importance of these findings is amplified by the amount of time that was spent by dental hygienists at the 8 o'clock position (>25%) during the simulated scaling task. This and the previous studies revealed static activity demands for the neck extensor (CES), trapezius (UT & LT) and thoracic erector spinae muscles exceeding the recommended occupational activation limits for an 8-h day (Jonsson 1982).

The low back and upper extremity physical demands appear to be an unavoidable requirement when scaling at the 8 o'clock position. Our recommendation would be that dental hygienists avoid or minimise the amount of time they spend working from the 8 o'clock position during manual scaling. The best working positions are between 10 and 11 o'clock due to the lower postural and muscular demands for the neck, shoulders and low back. If eliminating work at 8 o'clock in favour of working at either 10 or 11 o'clock is not practical, then an additional suggestion would be to work intermittently for shorter durations from the 8 o'clock position while scaling. This postural variability would reduce the prolonged periods of static loading by providing small rest breaks to the tissues that might experience heavier loads.

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