IIE Transactions on Occupational Ergonomics and Human Factors (2013), 1: 119–127

ISSN: 2157-7323 print / 2157-7331 online
DOI: 10.1080/21577323.2013.766282

ORIGINAL RESEARCH

Workday Arm Elevation Exposure: A Comparison Between Two Professions

Luke Ettinger,* Laurel Kincl, Peter Johnson, Cameron Carter, Sara Garfinkel, and Andrew Karduna
Department of Human Physiology, University of Oregon, 1240 University St., Eugene, OR 97403, USA

OCCUPATIONAL APPLICATIONS Results from this study indicate that dental hygienists spent a mean of 7% of their workday with their arms elevated above 60° of humeral elevation. The majority of their workday (71%) was spent working with their arms in static positions. Compared to a separate working population (office workers), dental hygienists had more than two times greater arm elevation exposure above 60°. Dental hygienists have a high incidence of shoulder injuries, which may be related to arm elevation exposure. Based on the present study, ergonomic interventions should be based on reducing the total arm elevation exposure in dental hygiene. Further, interventions should be designed to reduce the repetitive tasks performed by dental hygienists.

TECHNICAL ABSTRACT ***Background:*** The prevalence of shoulder-related musculoskeletal disorders among dental hygienists working in the United States has been reported to be between 21% and 60%. Arm elevation exposure levels above 60° have been identified as potentially harmful in other occupations. ***Purpose:*** The aim of this study was to measure arm elevation exposure in dental hygienists in a single workday and to compare these data with those from another occupation with a lower risk for shoulder impingement syndrome. ***Methods:*** Bilateral, full workday arm elevation exposure was measured for both dental hygienists and computer workers using a tri-axial accelerometer with a built in data logger (Virtual Corset®, Microstrain, Inc., VT, USA). Exposures analyzed were the percent of the workday spent above 30°, 60°, and 90° of humeral elevation. Additionally, exposure to repetitive motion, or jerk, was estimated, specifically the percent time spent moving the arm in pseudo-static (<10°/s) slow humeral motion (between 10°/s and 40°/s) and fast humeral motion (>40°/s). ***Results:*** Dental hygienists had bilateral arm elevations above 60° for approximately 7% of their workday, more than two times the exposure of office workers for the same duration of work. Dental hygienists had a mean of 71% of their work time in pseudo-static postures, which is significantly less than computer workers (78%). Dental hygienists had slow and fast arm motion during 23% and 6% of their workday, respectively, significantly higher than those for computer workers (17% and 5%). ***Conclusions:*** Arm elevation exposure levels among dental hygienists are relatively high and may contribute to

Received July 2012
Accepted January 2013

*Corresponding author. E-mail: lettinge@gmail.com

upper extremity injuries within this profession. In dental hygiene work, elevation exposure above 60° and dynamic arm motions above 10°/s may be specific contributors to the risk of upper extremity disorders bilaterally.

KEYWORDS Office ergonomics, dental hygiene, shoulder, posture, exposure assessment, biomechanics

INTRODUCTION

Exposure to work with arms in an elevated posture is believed to be related to degenerative changes of the rotator cuff tendons and may ultimately lead to such disorders as shoulder impingement syndrome (Armstrong et al., 1993). Occupations with high exposure to unsupported arm postures above 60° of elevation are considered injurious professions for the shoulder (Svendsen, Gelineck et al., 2004; Svendsen et al., 2005). In a study conducted by Bey et al. (2007), arm elevations were associated with geometric narrowing of the subacromial space; additionally, the subacromial distance was minimized when the arm reached 60° of humeral elevation. Narrowing of the subacromial space may be related to rotator cuff degeneration, shoulder pain, and subacromial impingement syndrome (Zuckerman JD, 1992; Nordt et al., 1999; Seitz et al., 2010). Narrowing of the subacromial space in combination with repetitive motion has been shown to accelerate rotator cuff tendon damage in a rat model (Soslowsky et al., 2002).

In the profession of dental hygiene, workers have a high estimated prevalence (64%–85% of active hygienists) of work-related shoulder pain (Akesson et al., 1999; Ylipaa et al., 2002). Constrained arm postures have been identified as potential risk factors for the development of occupational neck and shoulder disorders (Sartorio et al., 2005; Hayes et al., 2009; Morse et al., 2010). The incidence of shoulder injury in dental work may additionally be associated with the velocity of arm motion as well as the total amount of time the arm is exposed to elevated positions (Akesson et al., 1999; Marklin & Cherney, 2005). In addition to elevation exposure, greater generated muscle forces (intensity and duration) on the upper extremity during work are likely to lead to greater risk for injury (Bernard, 1997). Several factors may influence muscle force of the upper extremity in the workplace, such as external load (arms supported or unsupported during elevation), the degree of humeral elevation (where 90º elevation with respect to gravity results in maximal shoulder torque), the types of tools used during dental work, and the velocity of humeral movement.

Shoulder injuries are more commonly reported on the dominant arm of dental hygienists (Oberg T, 1993; Yee T & Harber, 2005). Marklin and Cherney (2005) evaluated bilateral arm elevations among dental workers using video recordings from 4-hour work sessions, and they found that dental hygienists maintain unsupported elevation of their left shoulder to a greater extent than their right (45% of workday left arm, 34% of workday right arm). Results from this study also suggested that exposure levels are greater in the non-dominant arm than the dominant arm of dental hygienists. However, previous work suggested that injury prevalence is greater on the dominant arm (Yee T & Harber, 2005). Based on the exposure analysis by Marklin and Cherney (2005), arm elevation exposure may not be sole factor in the development of shoulder injuries among dental hygienists. However, the aforementioned study did not compare arm elevation exposure by arm dominance, nor did it evaluate arm elevation exposure over the course of a full workday. Furthermore, the estimation of working postures through observation of two-dimensional video recordings is prone to parallax errors. Although there is no gold standard for measuring arm elevation exposure, recent studies have made similar measurements using triaxial accelerometers (Veiersted et al., 2008; Jonker et al., 2009; Hansson et al., 2010; Acuna & Karduna, 2012). Furthermore, several studies have identified an association between arm elevation exposure and shoulder injuries in jobs such as car mechanics, house painters, and machinists (Svendsen, Bonde et al., 2004; Svendsen et al., 2005). Yet, these studies were conducted in male-dominated occupations and did not take into account full workday bilateral elevation exposure (Svendsen, Bonde et al., 2004; Svendsen et al., 2005). To the authors' knowledge, no previous study has quantified bilateral arm elevation exposures for a full workday among dental hygienists–a female-dominated occupation. The paucity of research

regarding full workday arm elevation exposures and female workers limits the ability to design and implement effective ergonomic interventions.

The aim of this study was to compare arm elevation exposure and dynamic exposure between female dental hygienists and a separate population of female workers. Office workers who work primarily with computers are predominantly female and have relatively low risk for shoulder injuries (Jensen, 2003; Gerr et al., 2006; Waersted et al., 2010). A comprehensive review of musculoskeletal disorders among office workers (22 studies, 26 articles) showed insufficient casual evidence between computer use and shoulder injuries (Waersted et al., 2010). In a prospective cohort study of 896 newly employed workers from 12 different occupational settings, 12% (107 workers) complained of new-onset musculoskeletal pain. From this study, mechanical loading of the shoulder, unsupported arm elevation exposure to work above shoulder level, and repetitive work with little day to day variability in tasks were significantly correlated to new onset pain (Harkness et al., 2004). A typical workday for dental hygienists consists of four highly repetitive tasks–scaling, flossing, instrumentation, and polishing–that all require the arms to be predominantly unsupported (Bramson et al., 1998; Akesson et al., 1999; Marklin & Cherney, 2005). Office work is mostly comprised of repetitive computer tasks during which the arms are typically supported and maintain static positions for the majority of the workday (Eltayeb et al., 2009; Waersted et al., 2010). Both occupations have a lack of substantial day-to-day variation and are regarded as highly repetitive jobs. However, the reported shoulder injury rates between the two professions are dissimilar. For dental hygienists, between 21% and 60% of workers have reported should injuries (Lalumandier et al., 2001; Anton et al., 2002). In a study conducted by Hales et al. (1994), rotator cuff tendonitis was reported in less than 5% of computer workers. Disparity in injury rates between professions could be related to differences in arm elevation exposure and repetitive arm motion. Further, these differences could be due to ergonomic interventions already in place in office work, where it has been suggested that placing keyboards below elbow level, limiting head rotation, and supporting the arms during computer work may reduce risk for neck/shoulder injuries (Gerr et al., 2006). Simple ergonomic adjustments such as these may not be implemented easily in dental hygiene, where patient comfort and a dynamic changing work environment must be considered. It is thus hypothesized that dental hygienists will spend a greater percentage of their workday in elevated humeral angles and will work with their arms more dynamically than office workers. Furthermore, it was hypothesized that dominant arm exposures will be greater than nondominant arm exposures.

METHODS

Participants

Twenty-one female dental hygienists with a mean (range) age of 42.6 (24–56) years and with 16.7 (2–38) years of work experience participated in the study, along with 21 computer workers with a mean age of 42.6 (26–62) years. Computer workers were recruited to match the dental hygienist population for gender (all participants were female) and as closely as possible for age and arm dominance (both groups included 19 right-hand dominant workers and two left-handed individuals). Arm dominance was determined by asking participants which hand they would be more likely to use when throwing a ball. On the day of data collection, all participants worked at least 8 hours (dental hygienists mean 8.8 hours, computer workers mean 8.1 hours). All participants were required to work more than 20 hours per week. Prior to data collection, all participants signed an informed consent form approved by the university's institutional review board (IRB).

Before data collection, all participants completed a "disability of the arm, shoulder, and hand" (DASH) work module questionnaire (Kitis et al., 2009). DASH scores were out of 100 points, with 100 denoting inability to use normal work techniques and/or inability to perform work as normal due to shoulder pain within the past 12 months. For dental hygienists, the average DASH score was 10.4 (*SD* 17). For computer workers, the average DASH score was 3.5 (*SD* 9.4). The DASH questionnaires were analyzed using an independent samples *t*-test, where occupation was treated as the independent variable and DASH response was the quantitative dependent variable, $\alpha = 0.05$. In addition to the DASH questionnaire, workers were asked whether or not they had experienced a work-related shoulder injury during their career. A chi-squared analysis was used to test for differences between occupation and history of work-related shoulder injuries.

Instrumentation

To quantify humeral motion during the workday, Virtual Corset (VC; Microstrain, Inc., VT, USA) devices were fixed bilaterally to the arm of each participant. The VC is a pager-sized (6.8 × 4.8 × 1.8 cm), battery-powered tri-axial linear accelerometer with an 8-Mb built-in data logger. The overall mass of this device (including battery) is approximately 72 g. The sampling frequency of the accelerometer was 7.64 Hz.

Protocol

Before the start of the workday, the VC device was mounted bilaterally at the level of the deltoid tuberosity of the humerus using techniques previously validated (Amasay T, 2009). For calibration, the long axis (*z*-axis) of the VC was positioned on the arm to coincide with the long axis of the humerus, the orientation of the device was set as close to 0° as possible, as determined by the real-time feedback of the VC (Amasay T, 2009). Participants maintained a seated position and performed lateral trunk flexion towards the arm being instrumented, the participants arm were relaxed by their side while holding a 1 kg weight, which added an inferiorly directed force to help provide a flat attachment surface and align the arm vertically for the VC. Medical grade double sided tape, pre wrap and athletic tape were used to secure the device to the skin, and the position of the VC on the participant's arm was recorded using permanent marker. The process of VC calibration and fixation was repeated for both the dominant and non-dominant arms. After calibration, participants were instructed to proceed with work as normal (Fig. 1). At the end of the workday, the VC devices were removed and downloaded to a computer for later analysis. No participants complained of the VC interfering with their work from normal, and no devices were thought to have moved based on the skin during the workday based upon visual inspection of the final versus initial position of the VC on the participant's arm.

Data Analysis

Bilateral humeral elevation angles (θ) were calculated from the *x*-, *y*-, and *z*-acceleration (in units of g) outputs using the approach described by Amasay T et al. (2009): $\theta = \tan^{-1}\frac{\sqrt{x^2+y^2}}{z}$. RMS errors of the calculated elevation angles have previously been reported to be less than 1° in all axial rotations for the VC (Amasay T et al., 2009).

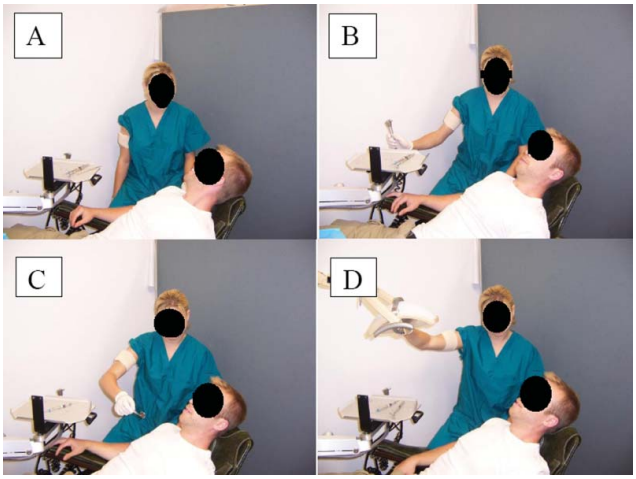

FIGURE 1 **Humeral elevation angles during typical dental work: (a) 0°, (b) 30°, (c) 60°, and (d) 90° elevation. Elevation angles were recorded using the VC, which was located on the arm at the level of the deltoid tuberosity of the humerus (color figure available online).**

Elevation data were analyzed using similar approaches to those reported earlier and which consisted of calculating the percent time spent above specific angles (i.e., 30°, 60°, and 90°) as well as the jerk time (Moller et al., 2004; Svendsen, Bonde et al., 2004; Marklin & Cherney, 2005; Mathiassen et al., 2005; Amasay et al., 2010; Hess et al., 2010). The total amount of time that the arm was maintained above each elevation angle was summed and divided by the elapsed time of the workday; this yielded, as dependent measures, the percentages of the workday spent above the specific humeral angles of 30°, 60°, and 90° of elevation (Fig. 1). The second dependent measure, jerk time, describes the total amount of time that the arm moved more (higher velocities) versus less (lower velocities) rapidly, and this is considered as a proxy for repetitive motion (Winkel et al., 1999; Moller et al., 2004; Mathiassen et al., 2005). Periods of dynamic arm posture were identified by first determining the number of temporally adjacent data points contained within distinct 10° elevation bins (0°–10°, 10°–20°, etc.). When the total number of points within a given bin corresponded to a duration of less than 1 second, the points were classified as dynamic; otherwise, they were classified as pseudo-static (Moller et al., 2004; Mathiassen et al., 2005; Amasay et al., 2010). Further, the jerk analysis separated slower from faster dynamic motion. Ultimately, elevation motions were categorized as

(Hess et al., 2010) pseudo-static (<10°/s), slow humeral motion (10°/s–40°/s), or fast humeral motion (>40°/s). The total number of data points in each category (static, slow, and fast) was converted to a percentage of the workday as dependent measures.

Arm elevation exposures were analyzed using a three-way, mixed-factor analyses of variance (ANOVA). The three qualitative independent variables were arm dominance (dominant and non-dominant), occupation (dental hygienists and office workers), and humeral elevation angle (30°, 60°, and 90°). Jerk data were analyzed using separate two-way, mixed-factor ANOVAs for each jerk category (static, slow, and fast), with independent variables of arm dominance and occupation. Post hoc *t*-test analysis were completed when significant main effects and interactions were found, with $\alpha = 0$ .05 using a Bonferroni correction.

RESULTS

Statistical Analysis, DASH Scores, and Shoulder Injury Questionnaire

There were no significant differences between dental hygienists ($M = 10.4$, $SD = 17.3$) and office workers ($M = 3.5$, $SD = 9.2$) in terms of current arm disability and/or pain (DASH questionnaire), $p = 0.119$. However, there were significant differences between dental hygienists and office workers in terms of history of work-related shoulder injuries, χ^2 (1, $N = 42$) = 9.02, $p = 0.003$. Fifty-two percent of dental hygienists (11/21) reported having had at least one shoulder injury during their career in dental hygiene. Of these injuries, 55% (6/11) resulted in medical treatment. For office workers, 9.5% of workers (2/21) reported having a work-related shoulder injury during their career in office work. For office workers, only one of the reported shoulder injuries required medical treatment. Additionally, from the questionnaire, scaling and flossing were reported to be the most physically taxing and fatiguing work activities on the shoulders of dental hygienists.

Percent Workday Above

A summary of the three-way ANOVA results is provided in Table 1; therefore, in this section, only significant findings are presented. A significant interaction was observed between humeral elevation angles and occupation on exposure ($p = 0.002$). Further significant main effects for both angle ($p = 0.001$) and occupation ($p = 0.002$) were detected. Three independent samples *t*-tests were used post hoc to test for bilateral occupational arm exposure differences at 30°, 60°, and 90° of humeral elevation. Post hoc comparisons indicate that bilaterally (collapsed by arm dominance), significant differences exist between dental hygienists and computer worker's arm elevation exposure above 30° and 60° but not above 90° (Table 2).

TABLE 1 Three-way ANOVA table for the effects of arm dominance, occupation, and arm elevation angle on percent of workday

ANOVA factor	*df*	*F*-Ratio	*P*-Value
Arm dominance	1	4.678	0.117
Elevation angle	2	91.561	0.001*
Occupation	1	12.922	0.002*
Arm dominance × elevation angle	4	0.790	0.468
Occupation × elevation angle	4	8.844	0.002*
Arm dominance × occupation	3	0.135	0.718
Arm dominance × occupation × elevation angle	6	0.496	0.672

Note. Asterisk denotes significant findings.

Jerk Analysis

No significant interactions were found between occupation and arm dominance for static ($p = 0.920$), slow ($p = 0.951$), or fast ($p = 0.851$) conditions. A significant main effect of occupation was found for all conditions (static, slow, and fast): $p < 0.001$, $p < 0.001$, and $p = 0.012$, respectively. There were no significant main effects of arm dominance for static ($p = 0.801$), slow ($p = 0.804$), or fast ($p = 0.808$) conditions.

TABLE 2 Summary of shoulder elevation exposures in the two populations

Assessed exposures	Dental hygienists	Computer workers	*P*-Value
Percent time >30°	32.8 (8.7)	23.2 (12.8)	0.009*
Percent time >60°	6.9 (3.6)	3.1 (2.3)	0.001*
Percent time >90°	2.6 (3.2)	1.4 (0.9)	0.116
Percent time static	70.8 (5.0)	77.5 (6.8)	0.001*
Percent time slow	23.0 (3.6)	17.2 (5.0)	0.001*
Percent time fast	6.2 (1.3)	5.3 (2.2)	0.012*

Notes. Values are means (*SD*) of results averaged across shoulders; asterisk indicates statistical significance.

DISCUSSION

It was hypothesized that dental hygienists would have greater arm elevation exposure and would work with faster arm velocities than office workers. The inclusion of computer workers served as a basis for comparison, since this group has relatively low rates of occupational shoulder injury. Results indicate that dental hygienists may spend as much as 7% of their workday with their arm elevated above 60° (Table 1). When compared to office workers, dental hygienists experienced more than two times the exposure duration to elevated arm postures above 60°, thus supporting the hypothesis. These differences suggest that dental hygienists have greater exposure to shoulder torque, given the larger elevation angles of the arm. Results additionally indicate that dental work requires less static arm postures than office workers, with greater arm usage at both slow and fast velocities. This latter finding suggests that dental hygienists are exposed to greater repetitive motion than office workers. No significant difference was found between occupations, in terms of current arm disability (DASH scores), although the dental hygienists reported having experienced five-fold more work-related shoulder injuries (52%) than computer workers (10%). The greater arm elevation exposure observed among dental hygienists may be related to this difference in injury, a difference that is consistent with earlier reports (Svendsen, Bonde et al., 2004; Marklin & Cherney., 2005).

Jobs requiring repetitive arm motions, especially above 60° of arm elevation, have an association with shoulder injuries (Svendsen, Bonde et al., 2004). Several studies have indicated that in dental work, elevated arm positions are common practice (Oberg T, 1993; Liss et al., 1995; Akesson et al., 1999). Dental hygienists have been found to spend as much as 10% of their workday above 60° of arm elevations and as much as 5% of their workday above 90° (Marklin & Cherney, 2005). Results here, however, indicate that dental hygienists experience less arm elevation exposure than previously predicted. The higher exposure levels reported in the previous study may be the result of measuring only a subset of the workday, as opposed to the full workday here. The present study gives evidence that the high occurrence of shoulder injury in dental work may be related to arm elevation exposure. Arm elevation angles above 60° have been associated with reductions in the anatomical space beneath the acromion process of the scapula (Bey et al., 2007). Reductions in subacromial distance has been suggested to play a role in the development of shoulder impingement syndrome as well as rotator cuff tears (Neer, 1972; Ludewig P, 2000). Further, during arm elevation, dental hygienists tend to anteriorly tilt their scapula, which may further reduce the subacromial distance, thus placing their shoulders at greater risk for injury (Ettinger et al., 2012).

For dental hygienists, 71% of the workday was spent with their arms working statically, and this was significantly less than that for office workers (78%). For dental hygienists, it has been reported that the arms typically maintain static but unsupported positions (Akesson et al., 2000). In a study conducted by Hansson et al. (2010), work at greater arm elevation angles, specifically above 60°, was described to be typically unsupported arm positions. Because dental hygienists spend significantly greater amounts of their workday above 60° and work with their arms less statically than office workers, they may also spend a greater percentage of their workday with their arms unsupported. To maintain unsupported arm positions, a high degree of coordinated muscle contraction from agonist and antagonist muscles groups is required, resulting in greater perceived muscle fatigue (Oberg et al., 1994). Occupational muscle fatigue may be associated with the development of workplace injuries (Bernard, 1997). In a study conducted by Oberg et al. (1995) electromyographic recordings from the trapezius muscle of dental hygienists during a workday indicated significant muscle fatigue as a result of their job-specific tasks (Oberg et al., 1995). We have recently reported that dental hygienists have potentially injurious changes in scapular kinematics due to a single bout of work exposure; this finding was found to interact with the total number of years of work exposure (Ettinger et al., 2011). It is possible that dental hygienists were fatigued by the workday, which resulted in changes to scapular kinematics (Ettinger et al., 2012). Furthermore, dental hygienists with more work exposure tend to exhibit greater changes in scapular kinematics, thus indicating that dental work exposure has a negative accumulative effect on shoulder neuromechanics (Ettinger et al., 2012). One possible solution to reduce work-related muscle fatigue is to support the working arm, thus reducing the torque experienced at the shoulder. Future work needs to investigate potential solutions to support the working arms of dental hygienists at elevated humeral angles, thus potentially reducing shoulder muscle strain.

Findings from the present study do not support the hypothesis with respect to arm dominance, since there were no arm dominance differences for full workday arm elevation, nor were there any significant dynamic arm usage differences between the dominant and nondominant arms of dental hygienists. Existing evidence suggests that arm injury rates among dental hygienists are not evenly split between the dominant and nondominant arms. For dental hygienists, injuries are 37% more common on the dominant side of right-handed dental hygienists and 94% more common on the dominant side of left-handed dental hygienists (Yee T & Harber, 2005). It is possible that other factors not measured in this study, such as external loads and instruments used for dental hygiene, may have an influence on shoulder injuries by arm dominance.

From the present study, dental hygienists had more shoulder injuries during their career and had greater arm elevation exposure levels than office workers. When compared with workers from other studies, dental hygienists have greater exposure levels than machinists but less exposure than car mechanics and house painters in terms of percent time above 30°, 60°, and 90° of humeral elevation (Svendsen, Bonde et al., 2004). Overall arm elevation exposure levels in female hairdressers was greater than exposure levels in dental hygienists (6.9% versus 13% of workday) for percent time above 60°; however, dental hygienists had greater arm elevation exposure levels than hairdressers (2.6 versus 2.1% of workday) for percent time above 90° (Veiersted et al., 2008). When compared with several relevant reports, the prevalence of shoulder complaints was greatest for the current dental hygienists than other groups, where 38% of dental hygienists (8/21) had at least one prior injury within the past 12 months. House painters had the second highest number of shoulder injuries, with roughly 32% (241/758) of workers having a shoulder injury within the past 12 months (Svendsen, Bonde et al., 2004). Hairdressers had the lowest number of injuries reported, with roughly 24% of workers reporting an injury (84/350) (Veiersted et al., 2008).

The use of tri-axial accelerometers can accurately quantify shoulder elevation exposure levels in dental hygienists (Amasay et al., 2010). In the current study, full workday arm elevation exposure levels varied between the two occupations tested. Study limitations include only sampling from a single workday from both dental hygienists and office workers. Further, as with any skin mounted device, skin motion artifact is a potential limitation. Care should be taken to ensure that devices mounted on skin do not move with respect to the skin during the workday.

Exposure to arm elevation above 30° and 60° in dental hygiene may be related to the relatively high prevalence of shoulder injuries in this field. Based on the results of the jerk analysis as well as information from the literature, it is likely that dental hygiene requires repetitive and unsupported arm positions, which may be fatiguing (Akesson et al., 2000; Oberg T, 1993). From this study's questionnaire, scaling and flossing were reported to be the most fatiguing work activities for the shoulder. It is possible that tasks such as scaling and flossing require more arm elevation exposure than other dental work tasks. Future studies should investigate the relationship between arm elevation exposures during specific dental tasks. Additionally, future studies could use a similar approach and devices to quantify full workday arm elevation exposure levels in other occupations with high occurrences of musculoskeletal injuries of the upper extremity. Implications of these future studies could help in the design of ergonomic interventions. Based on the current study, ergonomic interventions should be based on reducing the total arm elevation exposure and breaking up repetitive tasks during dental work.

CONFLICT OF INTEREST

The authors declare no conflict of interest. No funding or special circumstances influenced this work.

ACKNOWLEDGMENT

This research was partially supported by NIOSH (grant 5R010H008288).

REFERENCES

Acuna, M., & Karduna, A. R. (2012). Wrist activity monitor counts are correlated with dynamic but not static assessments of arm elevation exposure made with a triaxial accelerometer. *Ergonomics*, *55*(8), 963–970.

Akesson, I., Johnsson, B., Rylander, L., Moritz, U., & Skerfving, S. (1999). Musculoskeletal disorders among female dental personnel—clinical examination and a 5-year follow-up study of symptoms. *International Archives of Occupational and Environmental Health*, *72*(6), 395–403.

Akesson, I., Schutz, A., Horstmann, V., Skerfving, S., & Moritz, U. (2000). Musculoskeletal symptoms among dental personnel—lack of association with mercury and selenium status, overweight and smoking. *Swedish Dental Journal*, *24*(1–2), 23–38.

Amasay, T., Latteri, M., & Karduna, A. R. (2010). In vivo measurement of humeral elevation angles and exposure using a triaxial accelerometer. *Human Factors*, *52*(6), 616–626.

Amasay T, Z. K., Kincl, L., Hess, J., & Karduna, A. (2009). Validation of tri-axial accelerometer for the calculation of elevation angles. *International Journal of Industrial Ergonomics*, *39*, 783–789.

Anton, D., Rosecrance, J., Merlino, L., & Cook, T. (2002). Prevalence of musculoskeletal symptoms and carpal tunnel syndrome among dental hygienists. *American Journal of Industrial Medicine*, *42*(3), 248–257.

Armstrong, T. J., Buckle, P., Fine, L. J., Hagberg, M., Jonsson, B., Kilbom, A., Kuorinka, I. A., Silverstein, B. A., Sjogaard, G., & Viikari-Juntura, E. R. (1993). A conceptual model for work-related neck and upper-limb musculoskeletal disorders. *Scandinavian Journal of Work Environment and Health*, *19*(2), 73–84.

Bernard, B. (1997). Musculoskeletal disorders (MSDs) and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health (NIOSH), Report, 122–134.

Bey, M. J., Brock, S. K., Beierwaltes, W. N., Zauel, R., Kolowich, P. A., & Lock, T. R. (2007). In vivo measurement of subacromial space width during shoulder elevation: Technique and preliminary results in patients following unilateral rotator cuff repair. *Clinical Biomechanics (Bristol, Avon)*, *22*(7), 767–773.

Bramson, J. B., Smith, S., & Romagnoli, G. (1998). Evaluating dental office ergonomic. Risk factors and hazards. *Journal of the American Dental Association*, *129*(2), 174–183.

Eltayeb, S., Staal, J. B., Hassan, A., & de Bie, R. A. (2009). Work related risk factors for neck, shoulder and arms complaints: A cohort study among Dutch computer office workers. *Journal of Occupational Rehabilitation*, *19*(4), 315–322.

Ettinger, L., McClure, P., Kincl, L., & Karduna, A. (2012). Exposure to a workday environment results in an increase in anterior tilting of the scapula in dental hygienists with greater employment experience. *Clinical Biomechanics (Bristol, Avon)*, *27*(4), 341–345.

Gerr, F., Monteilh, C. P., & Marcus, M. (2006). Keyboard use and musculoskeletal outcomes among computer users. *Journal of Occupational Rehabilitation*, *16*(3), 265–277.

Hales, T. R., Sauter, S. L., Peterson, M. R., Fine, L. J., Putz-Anderson, V., Schleifer, L. R., Ochs, T. T., & Bernard, B. P. (1994). Musculoskeletal disorders among visual display terminal users in a telecommunications company. *Ergonomics*, *37*(10), 1603–1621.

Hansson, G. A., Arvidsson, I., Ohlsson, K., Nordander, C., Mathiassen, S. E., Skerfving, S., & Balogh, I. (2010). Physical workload in various types of work: Part 2. Neck, shoulder and upper arm. *International Journal of Industrial Ergonomics*, *40*, 267–281.

Harkness, E. F., Macfarlane, G. J., Nahit, E., Silman, A. J., & McBeth, J. (2004). Mechanical injury and psychosocial factors in the work place predict the onset of widespread body pain: A two-year prospective study among cohorts of newly employed workers. *Arthritis & Rheumatism*, *50*(5), 1655–1664.

Hayes, M., Cockrell, D., & Smith, D. R. (2009). A systematic review of musculoskeletal disorders among dental professionals. *International Journal of Dental Hygiene*, *7*(3), 159–165.

Hess, J. A., Kincl, L., Amasay, T., & Wolfe, P. (2010). Ergonomic evaluation of masons laying concrete masonry units and autoclaved aerated concrete. *Applied Ergonomics*, *41*(3), 477–483.

Jensen, C. (2003). Development of neck and hand-wrist symptoms in relation to duration of computer use at work. *Scandinavian Journal of Work Environment and Health*, *29*(3), 197–205.

Jonker, D., Rolander, B., & Balogh, I. (2009). Relation between perceived and measured workload obtained by long-term inclinometry among dentists. *Applied Ergonomics*, *40*(3), 309–315.

Kitis, A., Celik, E., Aslan, U. B., & Zencir, M. (2009). DASH questionnaire for the analysis of musculoskeletal symptoms in industry workers: A validity and reliability study. *Applied Ergonomics*, *40*(2), 251–255.

Lalumandier, J. A., McPhee, S. D., Parrott, C. B., & Vendemia, M. (2001). Musculoskeletal pain: Prevalence, prevention, and differences among dental office personnel. *General Dentistry*, *49*(2), 160–166.

Liss, G. M., Jesin, E., Kusiak, R. A., & White, P. (1995). Musculoskeletal problems among Ontario dental hygienists. *American Journal of Industrial Medicine*, *28*(4), 521–540.

Ludewig P, L. P. (2000). Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Physical Therapy*, *80* 276–291.

Marklin, R. W., & Cherney, K. (2005). Working postures of dentists and dental hygienists. *Journal of the California Dental Association*, *33*(2), 133–136.

Mathiassen, S. E., Nordander, C., Svendsen, S. W., Wellman, H. M., & Dempsey, P. G. (2005). Task-based estimation of mechanical job exposure in occupational groups. *Scandinavian Journal of Work Environment and Health*, *31*(2), 138–151.

Moller, T., Mathiassen, S. E., Franzon, H., & Kihlberg, S. (2004). Job enlargement and mechanical exposure variability in cyclic assembly work. *Ergonomics*, *47*(1), 19–40.

Morse, T., Bruneau, H., & Dussetschleger, J. (2010). Musculoskeletal disorders of the neck and shoulder in the dental professions. *Work*, *35*(4), 419–429.

Neer, C. (1972). Anterior acromioplasty for the chronic impingement syndrome in the shoulder. *Bone and Joint Surgery*, *54*, 41–50.

Nordt, W. E., 3rd, Garretson, R. B., 3rd, & Plotkin, E. (1999). The measurement of subacromial contact pressure in patients with impingement syndrome. *Arthroscopy*, *15*(2), 121–125.

Oberg, T., Karsznia, A., Sandsjo, L., & Kadefors, R. (1995). Work load, fatigue, and pause patterns in clinical dental hygiene. *Journal of Dental Hygiene*, *69*(5), 223–229.

Oberg, T., Sandsjo, L., & Kadefors, R. (1994). Subjective and objective evaluation of shoulder muscle fatigue. *Ergonomics*, *37*(8), 1323–1333.

Oberg T, O. U. (1993). Musculoskeletal complaints in dental hygiene: A survey study from sa Swedish county. *Journal of Dental Hygiene*, *5*, 256–261.

Sartorio, F., Vercelli, S., Ferriero, G., D'Angelo, F., Migliario, M., & Franchignoni, M. (2005). Work-related musculoskeletal diseases in dental professionals. 1. Prevalence and risk factors. *Giornale Italiano di Medicina del Lavoro ed Ergonomia*, *27*(2), 165–169.

Seitz, A. L., McClure, P. W., Finucane, S., Boardman, N. D., 3rd, & Michener, L. A. (2010). Mechanisms of rotator cuff tendinopathy: Intrinsic, extrinsic, or both? *Clinical Biomechanics (Bristol, Avon)*, *26*(1), 1–12.

Soslowsky, L. J., Thomopoulos, S., Esmail, A., Flanagan, C. L., Iannotti, J. P., Williamson, J. D., 3rd, & Carpenter, J. E. (2002). Rotator cuff tendinosis in an animal model: Role of extrinsic and overuse factors. *Annals of Biomedical Engineering*, *30*(8), 1057–1063.

Svendsen, S. W., Bonde, J. P., Mathiassen, S. E., Stengaard-Pedersen, K., & Frich, L. H. (2004). Work related shoulder disorders: Quantitative exposure-response relations with reference to arm posture. *Occupational and Environmental Medicine*, *61*(10), 844–853.

Svendsen, S. W., Gelineck, J., Mathiassen, S. E., Bonde, J. P., Frich, L. H., Stengaard-Pedersen, K., & Egund, N. (2004). Work above shoulder level and degenerative alterations of the rotator cuff tendons: A magnetic resonance imaging study. *Arthritis & Rheumatism*, *50*(10), 3314–3322.

Svendsen, S. W., Mathiassen, S. E., & Bonde, J. P. (2005). Task based exposure assessment in ergonomic epidemiology: A study of upper arm elevation in the jobs of machinists, car mechanics, and house painters. *Occupational and Environmental Medicine*, *62*(1), 18–27.

Veiersted, K. B., Gould, K. S., Osteras, N., & Hansson, G. A. (2008). Effect of an intervention addressing working technique on the biomechanical load of the neck and shoulders among hairdressers. *Applied Ergonomics*, *39*(2), 183–190.

Waersted, M., Hanvold, T. N., & Veiersted, K. B. (2010). Computer work and musculoskeletal disorders of the neck and upper extremity: A systematic review. *BMC Musculoskeletal Disorders*, *11*, 79.

Winkel, J., Christmasson, M., Cyren, H., Engström, T., Forsman, M., Hansson, G. A., Hanse, J. J., Kadefors, R., Mathiassen, S. E., Medbo, L.,

Möller, T., Ohlsson, K., Petersson, N. F., Skerfving, S., & Sundin, A. (1999). A Swedish industrial research program 'Co-operative for Optimization of Industrial Production Systems Regarding Productivity and Ergonomics' (COPE). *American Journal of Industrial Medicine, Supplement 1*, 82–85.

Yee T, C. L., & Harber P. (2005). Work environment of dental hygienists. *Journal of Occupation Environ Med.*, *6*, 633–639.

Ylipaa, V., Szuster, F., Spencer, J., Preber, H., Benko, S. S., & Arnetz, B. B. (2002). Health, mental well-being, and musculoskeletal disorders: A comparison between Swedish and Australian dental hygienist. *Journal of Dental Hygiene*, *76*(1), 47–58.

Zuckerman JD, K. F., & Cuorno F. (1992). The influence of coracoacromial arch anatomy on rotator cuff tears. *Journal of Shoulder and Elbow Surgery*, *1*, 4–14.