International Journal of Industrial Ergonomics 44 (2014) 253–259

Contents lists available at SciVerse ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Risk of neck musculoskeletal disorders among males and females in lifting exertions

Ashish D. Nimbarte*

Industrial and Management Systems Engineering, PO Box 6070, West Virginia University, Morgantown, WV 26506-6107, USA

ARTICLE INFO

Article history:
Received 26 June 2012
Received in revised form
16 October 2012
Accepted 23 January 2013
Available online 21 February 2013

Keywords:
Musculoskeletal disorders
Neck
Gender
Lifting
Electromyography

ABSTRACT

Work-related neck disorders are common among various occupational groups. Despite clear epidemiological evidence for the association of these disorders with forceful arm exertions, the effect of such exertions on the biomechanical behavior of the neck muscles is currently not well understood. In this study, the effect of lifting tasks on the biomechanical loading of neck muscles was investigated for males and females. Twenty-six participants (13 males and 13 females) performed bi-manual isometric lifting tasks at knuckle, elbow, shoulder, and overhead heights by exerting 25%, 50%, and 75% of their maximum strength. The activity of the cervical trapezius and sternocleidomastoid muscles was recorded bilaterally using surface electromyography. Higher activity of the cervical trapezius muscle (10% MVC–43% MVC) compared to the sternocleidomastoid muscle (4% MVC–18% MVC) was observed. Females tend to use the sternocleidomastoid muscle to a greater extent than males, whereas, higher cervical trapezius muscle activation was observed for males than females. The main effect of weight and height, and weight by height interaction on the activity of neck muscles was statistically significant (all $p < 0.001$). The results of this study demonstrate that the neck muscles play an active role during lifting activities and may influence development of musculoskeletal disorders due to resulting physiological changes.

Relevance to industry: Lifting and forceful arm exertions are common at workplaces. The effect of lifting tasks on the biomechanical loading of neck muscles was evaluated in this study. Understanding this effect would improve our pathophysiological understanding of neck WMSDs caused by physically demanding exertions. This will further facilitate development of workplace intervention to modify workplace methods and/or designs so that incidences of neck WMSDs caused by lifting and forceful arm exertions could be minimized.

1. Introduction

Work-related musculoskeletal disorders (WMSDs) are the nontraumatic soft tissue disorders that are caused and/or exacerbated by workplace exertions. One-third or more of registered occupational diseases in the United States, Canada, the Nordic countries, and Japan are caused by WMSDs (Punnett and Wegman, 2004). These disorders require more days away from work than any other group of occupational diseases (National Research Council, 2001). In 2010, WMSDs in the United States accounted for 29% of the injuries and illnesses requiring a median of 10 days away from work, a percentage that has not changed a lot since 2005 (BLS, 2011). The annual cost of WMSDs as measured by compensation costs, lost wages, and lost productivity, are between $45 and $54 billion annually (Dunning et al., 2010). Regardless of the actual dollar cost, the impact of WMSDs is enormous in terms of individual health and corporate economics.

WMSDs of the neck and/or cervical spine result in longer sick leaves, constitute a substantial level of human suffering, and contribute significantly to morbidity among various working populations (Hales and Bernard, 1996). In a recent report by the Task Force of Bone and Joint Decade, a wide range of neck pain prevalence across different occupations and populations was reported, from 4.8% for Mexican males in shoe-making factories to 50.8% in California drivers. Among the general population, annual prevalence of neck pain ranged between 27.1% in Norway to 33.7% in the U.K. to 48% in Quebec, Canada (Côté et al., 2008). Epidemiological studies identify various work-related physical exertions as the possible risk factors for the development of neck WMSDs. Walker-Bone and Cooper (2005) presented a review of epidemiological studies on soft tissue musculoskeletal disorders of the neck and upper extremity among a wide range of occupations. The studies

* Tel.: +1 304 293 9473; fax: +1 304 293 4970.
E-mail addresses: Ashish.Nimbarte@mail.wvu.edu, nimbarte.ashish@gmail.com.

0169-8141/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ergon.2013.01.007

listed in the Embase and Medline databases performed during 1998–2001 were included in this review. An association between neck pain and prolonged abnormal posture, forceful and/or repetitive arm exertions, was reported by the authors. Malchaire et al. (2001) reviewed 57 cross-sectional and seven longitudinal studies concerning neck and upper limb musculoskeletal disorders. A majority of the studies reported a clear association between physical workload or force, awkward posture, and repetitiveness and musculoskeletal disorders of the neck and shoulder. Based on a review of 22 cross-sectional studies, two prospective cohort studies, and one case-referent study, Ariens et al. (2000) found evidence for a positive relationship between neck pain and work-related exertions that demand awkward head, trunk, and arm postures, arm force, and prolonged sitting.

A few experimental studies have further investigated the effects of the aforementioned risk factors on the biomechanical loading of the neck and shoulder musculature. A majority of these studies focused on awkward head–neck postures typically used during computer work, sewing machine operation, and dental work. Flexed head–neck postures adopted during such work activities were linked with increased muscular load and fatigue of the neck extensor muscles (Åkesson et al., 2011; Jensen et al., 1993; Turville et al., 1998; Villanueva et al., 1997). Repetitive arm movements and static neck posture used in assembly tasks and cash register use were found to generate neuromuscular fatigue and discomfort in the neck and shoulder musculature (Bosch et al., 2007). However, no studies have examined the effect of forceful arm exertions on the behavior of the neck musculature. While forceful arm exertions and/or heavy lifting have been traditionally associated with lower back disorders, existing studies mostly focus on the effect of such exertions on the lumbar spine. However, epidemiological literature clearly indicates that neck or cervical spine disorders or disc-specific pathologies such as disc herniation, cervical syndrome, and cervical myelopathy (Hagberg and Wegman, 1987; Larsson et al., 2007) are common among workers in industries that demand forceful arm exertions or heavy lifting. These include construction (Silverstein et al., 2002), healthcare (Lipscomb et al., 2004; Trinkoff et al., 2003), agriculture (Aublet-Cuvelier et al., 2006; Rosecrance et al., 2006), transportation and warehousing (Silverstein et al., 2002), and manufacturing (Chee and Rampal, 2004). These pathological conditions mostly involve impingement of nerves and the spinal cord passing through the cervical spine, and are associated with pain and discomfort in many cervical tissues including neck muscles, intervertebral discs, posterior longitudinal ligament, and facet joints (Bland, 1994; Cailliet, 1981; Jeffreys, 1993).

In addition to the above-stated physical work-related factors, gender has been listed as one of the most predominant non-modifiable risk factors of WMSDs of the neck (Hogg-Johnson et al., 2008). A higher prevalence of work-related neck pain was reported among females than males (Côté et al., 2008; Fejer et al., 2006; Widanarko et al., 2011). Different physical features (e.g., anthropometry, strength, flexibility, pain tolerance, endurance, etc.) affect the work methods used by females in order to balance work demands with work ability, which may increase the risk of WMSDs for females more than males (Dahlberg et al., 2004). A few previous studies have shown that during repetitive and/or sub-maximal motions, females use different upper extremity kinematics and encounter higher joint motion stressfulness than males (Kee, 2005; O'Sullivan and Gallwey, 2002). More strenuous forward tilted postures were also reported for female computer users than males (Straker et al., 2011). However, currently, there is a lack of data that translate how the physical differences and the altered work methods used by females affect their biomechanical response of neck and shoulder muscles to the physically demanding workloads.

As noted, the effect of forceful arm exertions on the biomechanical response of neck muscles and the role played by the gender in this response is currently not well understood. Therefore, the aims of this study were twofold. First, quantify the biomechanical loading of neck muscles during isometric lifting tasks performed at various working heights and weight conditions. Second, assess how the gender difference further influences the response of neck muscles to these isometric lifting exertions. It was hypothesized that conditions of the lifting task (e.g., weight, height) will significantly affect the biomechanical loading of neck muscles and that the relationship between the external work-related exertions and the internal loading of neck muscles will be inconsistent between the males and females.

2. Methods

2.1. Participants

Twenty-six healthy participants (13 males and 13 females) were recruited for data collection. The average age, weight, and height of the participants were 22.7 $\pm$ 2.2 years, 75.2 $\pm$ 16.7 kg, and 170.9 $\pm$ 9.8 cm, respectively. The following inclusion and exclusion criteria were used in this study: (1) participants are free from any type of musculoskeletal disorders; (2) they had no history of neck injury or notable neck pain. The Physical Activity Readiness Questionnaire (PAR-Q, Canadian Society for Exercise Physiology) was used to screen participants for cardiac and other health problems (e.g., dizziness, chest pain, heart trouble). Participants who met the inclusion criteria were asked to read and sign a consent form approved by the local Institutional Review Board.

2.2. Apparatus/Tools

2.2.1. Electromyography (EMG) system

Activity of the neck muscles was recorded using a Bagnoli-16 desktop EMG system (Delsys Inc., Boston, USA). The surface electrodes used were parallel bar, active surface electrodes (DE-2.3 EMG Sensors, Delsys Inc., Boston, USA). The sensor contacts are made from 99.9% pure silver bars, measuring 10 mm in length, 1 mm in diameter and spaced 10 mm apart. The common-mode rejection ratio (CMRR) for the electrodes is 92 dB and input impedance is greater than 10^{15} Ω. The frequency of EMG data acquisition was set to 1000 Hz.

2.2.2. Isometric strength measurement device

This device was used to measure maximum lifting strengths at different lifting heights. It consists of a column and base assembly (Fig. 1). A horizontal lever arm is mounted on the column. This lever arm moves up and down along the column and can be fixed at any position. A force measurement device consisting of a load cell–handle assembly is mounted on the horizontal lever arm (Fig. 1(a)). The output of the load cell was recorded using a force monitor (ST-1, Prototype Design and Fabrication Company, Ann Arbor, MI, USA). This device was also used to standardize location of load with respect to the participants during the isometric lifting tasks by replacing the load cell–handle assembly with a small wooden board to carry a box (Fig. 1(b)).

2.3. Experimental design

A 4 $\times$ 3 full factorial experimental design was used. Factor 1, lifting height, was treated at four fixed levels: (1) Knuckle height; (2) Elbow height; (3) Shoulder height; and (4) Overhead height. Factor 2, lifting weight, was treated at three fixed levels: (1) 25%; (2)

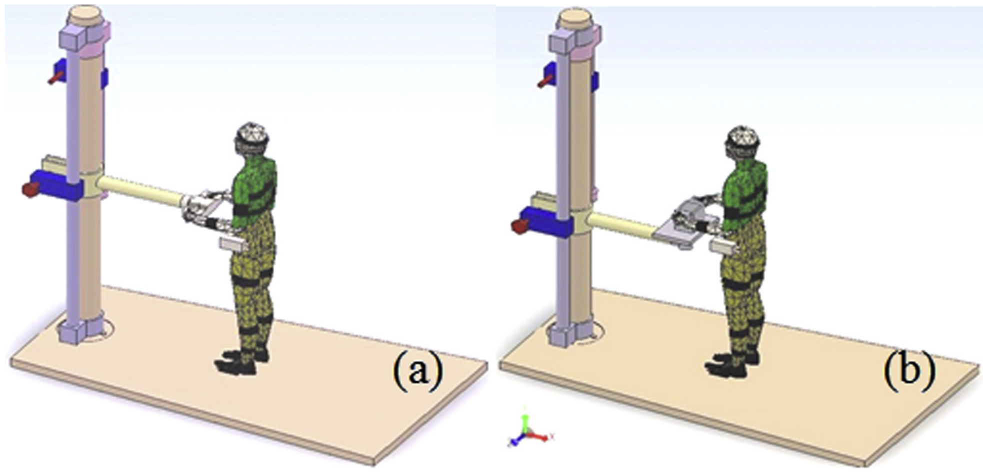

Fig. 1. Schematic of a participant using isometric strength measurement device to perform (a) maximal isometric lifting test and (b) isometric lifting task at the elbow height.

50%; and (3) 75% of individual maximum strength. Three replications were used and the trial order was randomized.

2.4. Data collection

Upon arriving at the laboratory, participants were given a tour of the experimental set-up. Equipment, data collection procedures, and specifics of the experimental tasks were explained to them and basic demographic and anthropometric data were recorded. Subsequently, the following stepwise procedure was used to collect the experimental data.

2.4.1. EMG data collection preparation

Surface electromyography (SEMG) data were recorded from the sternocleidomastoid (major anterior neck muscle) and the cervical trapezius (major posterior neck muscle) muscles. For the sternocleidomastoid muscle, an SEMG electrode was placed at 1/3 the distance between the mastoid process to the sternal notch, from the mastoid process (Nimbarte et al., 2010). SEMG from the cervical trapezius muscle was measured by placing an electrode between the occipital and the C7, at the level of C4 (approximately the mid-cervical region). The level of C4 was determined by marking a horizontal line at 2.5 times the distance between the C6 and C7 vertebrae above the C7. The electrode at this location was placed slightly inclined (approximately 35°) to the vertical line between C7 and C4 (Nimbarte et al., 2010, 2012). The skin underneath the anatomical landmarks was shaved (if needed), abraded, and cleaned with 70% alcohol, prior to the placement of the SEMG electrodes. SEMG data were collected bilaterally.

2.4.2. Maximum strength and neck muscle MVC measurement

The maximum lifting strength at the knuckle, elbow, shoulder, and overhead heights was determined using the strength measurement apparatus (Fig. 1). During the maximal exertions, participants were instructed to generate force slowly and steadily without a jerking motion until the maximum exertion is reached. The maximal exertion was maintained for a duration of 3–5 s. A rest period of up to two minutes was provided between the exertions (Sommerich et al., 2000). Three trials were collected for each type of exertion. If variability in the average force between the trials of same exertion was >10%, a fourth trial was performed and the average of the three closest values was used (Aghazadeh et al., 1997). Subsequently, participants performed isometric head flexion and bending tasks as described in our previous study (Nimbarte et al., 2010) to record neck muscle activation at MVC.

2.4.3. Lifting exertions

During this step, participants performed isometric lifting exertions at various weight and height conditions. The upper extremity joint configurations used during these exertions are shown in Fig. 2. During each exertion, the participant stood in the normal upright standing posture with her/his feet placed symmetrically and shoulder width apart. Two wooden boxes with cutout handles were used to perform the lifting exertions. Participants with a shoulder width less than 35 cm performed the lifting tasks using a 30 cm wide box (30 cm × 30 cm × 20 cm), while the participants with a shoulder width more than 35 cm used a 42 cm wide box (25 cm × 42 cm × 20 cm). The weights of the boxes were adjusted to the target weight by using metal pieces of various masses. During a lifting exertion, the height of the box was adjusted to the target height (by moving the horizontal lever arm of the strength measurement device (Fig. 1(b))) such that the required joint configuration was achieved. Manual goniometers were used to maintain consistent joint configurations across the participants. The duration of a lifting exertion was approximately 7 s: the initial 2 s for lifting the box and the remaining 5 s for holding the box. A rest period of up to 1 min was provided between the lifting exertions.

2.5. Data processing

EMG data during the 5 s of box holding was processed to calculate mean absolute values (MAV). The raw EMG signal from each electrode location was demeaned and full-wave rectified. The full-wave rectified EMG signal was low pass filtered at 4 Hz, using a fourth-order dual pass Butterworth digital filter, to form a linear envelope (Burnett et al., 2007). The resulting data was averaged and normalized with respect to the MVC contraction as explained in our previous study (Nimbarte et al., 2010) to determine the Normalized MAV (N-MAV).

2.6. Statistical analysis

A three-factor general linear ANOVA was performed to evaluate the effect of lifting height, weight, and gender on the activities of the neck muscles. Lifting height, weight, and gender were treated as fixed effects and subjects as a random factor. Subject was nested

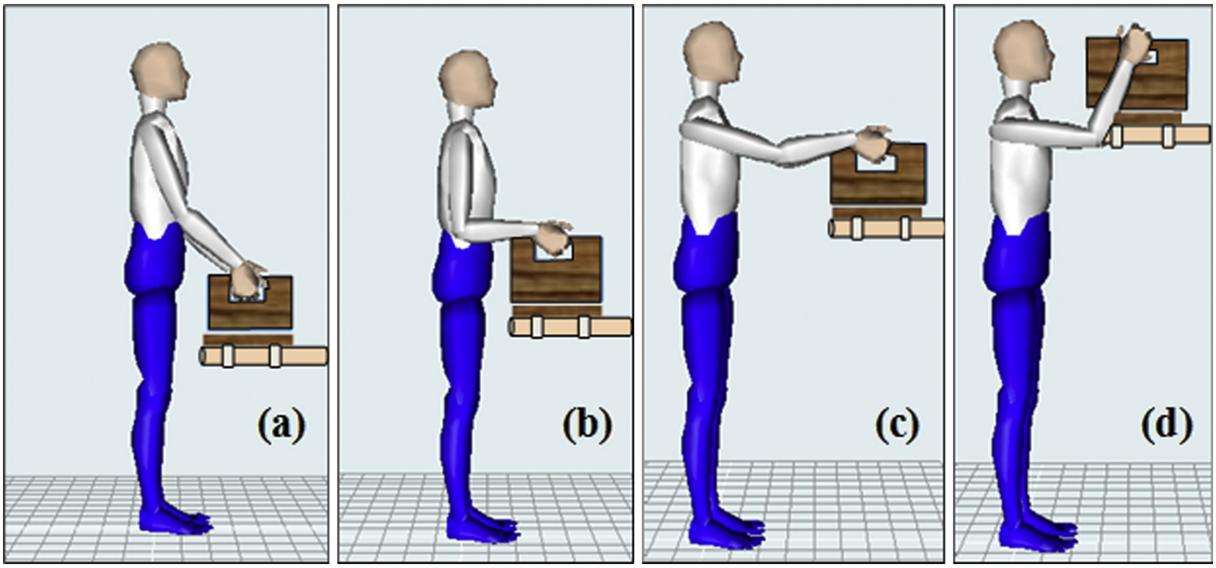

Fig. 2. Joint configurations used by the participants to perform isometric lifting tasks at (a) knuckle, (b) elbow, (c) shoulder, and (d) overhead heights.

in gender. Significance level was set to 95%. The adequacy of the linear model was confirmed by normal probability plots of the residuals between the actual and fitted value. Minitab 16 software (Minitab Inc., Pennsylvania, USA) was used to perform the statistical analysis.

3. Results

The average isometric strengths of males at knuckle, elbow, shoulder, and overhead heights were 170.4 (22.7), 249.7 (59.4), 136.7 (32.3), and 267.2 (70.9) N, respectively. The corresponding strengths of females at the respective heights were 127.6 (27.6), 159.3 (33.7), 95.9 (21.6), and 178.9 (49.4) N (Fig. 3). The strengths of males at different heights were significantly higher than females (all $p < 0.001$).

The main effect of gender on the activity of sternocleidomastoid ($p < 0.001$) and cervical trapezius ($p < 0.001$) muscles was statistically significant (Table 1). The mean activity of the sternocleidomastoid muscle of females was higher than males at different weight and height conditions (Fig. 4). On the contrary, activity of the cervical trapezius muscle of males was higher than females (Fig. 4).

The main effect of weight and height, and weight by height interaction on the activity of the sternocleidomastoid (all $p < 0.001$) and cervical trapezius (all $p < 0.001$) muscles was statistically significant (Table 1). For the sternocleidomastoid muscle, the effect of weight was minimal (increase of 0.2% MVC–2% MVC) at knuckle and elbow heights. A somewhat noticeable effect of weight (increase of 3% MVC–7% MVC) was observed at shoulder and overhead heights. At different weight conditions, the activity of sternocleidomastoid muscle increased in the range of 0.2% MVC–1.4% MVC for the change in the height from knuckle to elbow (Fig. 4). A relatively higher increase in the range of 1% MVC–4% MVC and 2% MVC–7% MVC was observed for the change in the height from elbow to shoulder, and from shoulder to overhead, respectively (Fig. 4).

For the cervical trapezius muscle, a much higher activation compared to the sternocleidomastoid muscle was observed. Like the sternocleidomastoid muscle, the effect of weight for the cervical trapezius muscle was higher at the shoulder and overhead heights than knuckle and elbow heights (Fig. 4). An increase in the range of 1% MVC–3% MVC, 4% MVC–5% MVC, 8% MVC–11% MVC, and 12% MVC–13% MVC, was observed for the increase in the weight from 25% to 50% to 75% at the knuckle, elbow, shoulder, and overhead heights, respectively. At different weight conditions, the highest increase in the activity of cervical trapezius muscle was observed for a change in the lifting height from elbow to shoulder (7% MVC–16% MVC) followed by a change in the lifting height from knuckle to elbow (2% MVC–8% MVC). Unlike the sternocleidomastoid muscle, a minimal change in the activity of cervical trapezius muscle was observed for the increase in the lifting height from shoulder to overhead (0% MVC–6% MVC) (Fig. 4).

4. Discussion

In this study, the effect of isometric lifting exertions on the biomechanical loading of neck muscles was investigated for males and females using surface electromyography. Muscles in the posterior part of the neck, i.e., cervical trapezius muscles, have shown higher activity (% MVC) than the anterior neck muscles, i.e., sternocleidomastoid muscles. Females tend to use sternocleidomastoid muscles to a greater extent than males, whereas, higher cervical trapezius muscle activation was observed for males than females. A continuous increase in the activity of the sternocleidomastoid muscle was observed with the increase in the lifting weight and heights, and the highest activity was observed at the overhead height for the heavy weight (75% strength) condition. But, for the cervical trapezius muscle, activity increased from knuckle to shoulder heights and remained almost unchanged between shoulder and overhead heights for different weight conditions.

The observed gender-specific trend in the muscle activation pattern seems to indicate that females may have used different force exertion strategies than males during the isometric lifting tasks. The two pairs of muscles tested in this study represent the major anterior and posterior neck muscles. These muscles, in addition to supporting head motions, connect shoulder joints with the skull. The three joints that constitute the shoulder complex include glenohumeral, acromioclavicular, and sternoclavicular joints. The sternocleidomastoid muscle originates at the sternoclavicular joint, with medial and lateral heads located at the manubrium of the sternum and the superior–anterior surface of the medial third of the clavicle, respectively. The insertion for the sternocleidomastoid muscle is the lateral surface of the mastoid process. The cervical trapezius muscle

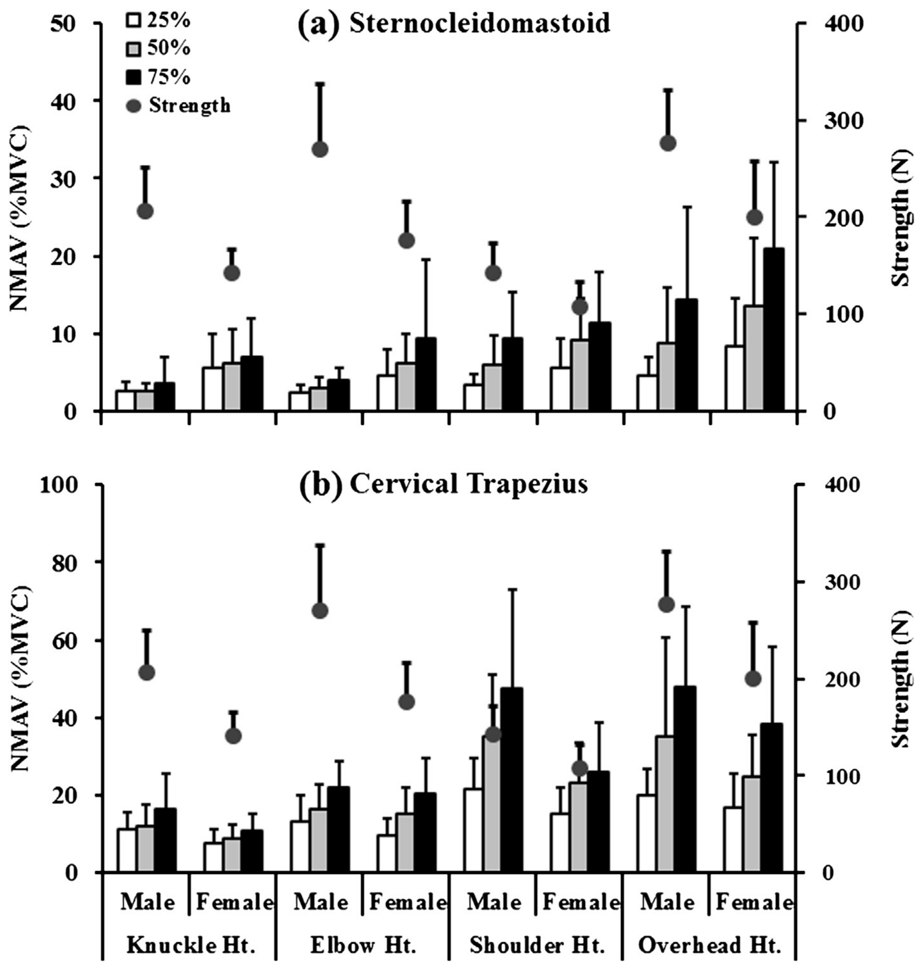

Fig. 3. Mean activity of (a) sternocleidomastoid and (b) cervical trapezius muscles during isometric lifting tasks performed at different weight and height conditions. The primary axes to the left of the charts represent muscle activity (plotted using bars) expressed in Normalized Mean Absolute Values (N-MAV (% MVC)) and the secondary axes on the right side of the charts represent strength (plotted using circles). Error bars represent one standard deviation.

originates at the external occipital protuberance and inserts at the lateral third of clavicle and acromion of scapula. The articulation between the lateral aspect of clavicle and acromion of scapula forms the acromioclavicular joints. Higher activation of sternocleidomastoid muscle than cervical trapezius muscle for females appears to indicate that females used the sternoclavicular joint to a greater extent than the acromioclavicular joints to balance the net reaction moment during the isometric lifting tasks. Lower strength of the acromioclavicular joint for females than males may attribute to this distinction in the muscle activation pattern. In general, higher shoulder strength was reported for males than females (Chaffin et al., 1991), but the strength of isolated shoulder joints is not known. The proposed lower strength of the acromioclavicular joint for females may have required increased load sharing by the sternoclavicular joint, and therefore, higher activity of the sternocleidomastoid muscle was observed for females compared to males.

Table 1
Main effect of gender, weight and height on the activity of neck muscles (% MVC).

		Gender			*p*-value
		Male	Female		
Sternocleidomastoid		5.3 (5.8)	8.9 (7.7)		<0.0001
Cervical trapezius		24.9 (18.5)	18.0 (12.5)		<0.0001
	Height (Ht)				*p*-value
	Knuckle	Elbow	Shoulder	Overhead	
Sternocleidomastoid	4.5 (3.9)	4.8 (5.1)	7.4 (5.4)	11 (9.8)	<0.0001
Cervical trapezius	11.2 (5.8)	16.1 (7.7)	28.1 (17.6)	30.4 (19.6)	<0.0001
	Weight (Wt)				Ht × Wt
	25%	50%	75%	*p*-value	*p*-value
Sternocleidomastoid	4.5 (3.7)	6.8 (5.9)	9.9 (9.3)	<0.0001	<0.0001
Cervical trapezius	14.4 (7.6)	21.3 (15.2)	28.6 (19.8)	<0.0001	<0.0001

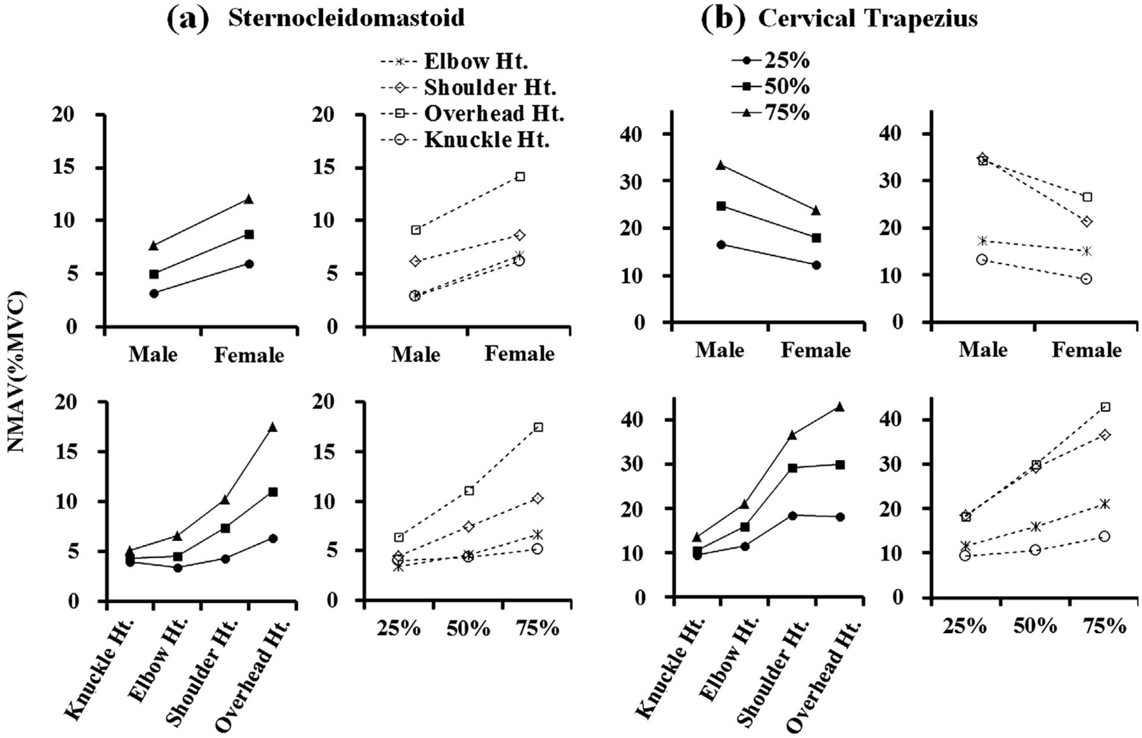

Fig. 4. Interaction effect of lifting weight, height and gender on the activity of neck muscles.

Some distinction in the activity pattern of neck muscles with respect to the lifting heights was observed in the pooled data. As expected, the sternocleidomastoid muscle showed the highest increase in the activity (average 54% increase) for the increase in the height from shoulder to overhead, but, a minimal change (average 5% increase) in the activity of the cervical trapezius muscle was observed for this height change. Previous studies have reported high activation (up to 60% MVC–75% MVC) of the upper trapezius muscle for forceful arm exertions, especially when performing over shoulder/head heights (Nimbarte et al., 2010, 2011, 2012). The fibers of the upper trapezius muscle originate in the C7–T3 vertebrae and insert in the acromion process and the spine of scapula. When working over shoulder/head heights, the acromioclavicular joint elevates and retracts and may activate the upper trapezius muscle to a greater extent than the cervical trapezius muscle. This increased activation by the upper trapezius muscle may have compensated for the increased force demand during lifting tasks performed above shoulder and/or head heights, keeping the activity of cervical trapezius muscle unchanged.

Although lower isometric lifting strength of females than males was observed in this study, both groups showed the highest strength at overhead height followed by the elbow, knuckle and shoulder heights. Based on the pooled data, on average, a 6 kg increase in the weight at the overhead height increased the activity of sternocleidomastoid and cervical trapezius muscles by 4% MVC–6% MVC and 11% MVC–13% MVC, respectively. At shoulder height, a 3 kg increase in the weight increased the corresponding muscle activation levels by 2% MVC–3% MVC and 7% MVC–10% MVC, respectively. A very low increase in the muscle activity (range 0.2% MVC–5% MVC) was observed for an average of 5 kg weight increase at elbow and knuckle heights. Overall, the ratios of % MVC increase to lifting weight increase indicate that weight change produced much higher increase in the % MVC at the shoulder height, followed by the overhead, elbow, and knuckle heights.

The % MVC levels for neck muscles observed in this study were higher than the recommended WMSDs risk threshold of 30% MVC (Hagberg, 1984; Larsson et al., 2007, 1990) for cervical trapezius muscle at the shoulder and overhead heights for medium (50% strength) and heavy (75% strength) weight conditions. For sternocleidomastoid muscle, activation in the range of 8% MVC–17% MVC was observed at the same weight and height conditions. However, the muscle activity data in this study was recorded using weights that were adjusted for gender based on their strength. On average, males exerted forces that were 1.3–1.5 times higher than females. Under the fixed weight condition, which is common in the real world situation, higher muscle activation is expected for female workers. Furthermore, in this study, lifting tasks were performed in neutral neck postures. A 2- to 4-fold increase in the activation levels of neck muscles was observed at non-neutral flexed and extended neck postures (Nimbarte et al., 2010).

There are a few limitations of this study that need to be acknowledged. First, a convenient sample of students in the engineering college was used. These participants may have minimal manual material handling experience and it is possible that the lifting strength of these participants is lower than experienced workers and they may have used different lifting strategies. Furthermore, considering the preliminary and exploratory nature of this study, the experimental conditions were standardized using fixed weights and heights. Forceful arm exertions at actual workplaces are characterized by more complex head–trunk posture and are mostly dynamic in nature. Future study should use experienced workers and test more representative forceful exertions to improve our overall understanding of neck WMSDs caused by forceful arm exertions.

5. Conclusion

Work-related lifting and forceful exertions are epidemiologically associated with WMSDs of the neck or cervical spine. However, the biomechanical effect of such exertions on the behavior of neck muscles has not been studied previously. The current study demonstrates that neck muscles play an active role in isometric lifting tasks. Response of neck muscles to the lifting tasks was also found to be dependent on the gender. Distinct and noticeable trends in the activation pattern of anterior versus posterior neck muscles with respect to lifting heights were also observed. Finally, this study provides empirical evidence for causative relationship between the WMSDs of neck or cervical spine and forceful arm exertions.

References

Aghazadeh, F., Waly, S., Nason, J., 1997. Static and Dynamic Strengths of Males and Females in Seating and Standing Postures. Advances in Occupational Ergonomics and Safety, pp. 293–296.

Åkesson, I., Balogh, I., Hansson, G.Å., 2011. Physical workload in neck, shoulders and wrists/hands in dental hygienists during a work-day. Applied Ergonomics 43, 803–811.

Ariens, G.A.M., Van Mechelen, W., Bongers, P.M., Bouter, L.M., Van Der Wal, G., 2000. Physical risk factors for neck pain. Scandinavian Journal of Work, Environment & Health, 7–19.

Aublet-Cuvelier, A., Aptel, M., Weber, H., 2006. The dynamic course of musculoskeletal disorders in an assembly line factory. International Archives of Occupational and Environmental Health 79, 578–584.

Bland, J.H., 1994. Basic Anatomy. Disorders of the Cervical Spine: Diagnosis and Medical Management, second ed. Saunders, Philadelphia, Pa, pp. 41–70.

BLS, 2011. Nonfatal occupational injuries and illness requiring days away from work for state government and local government workers. In: Economics Release (Ed.), U.S. Department of Labor, Feb 24th ed. BLS, p. 7.

Bosch, T., De Looze, M., Van Dieen, J., 2007. Development of fatigue and discomfort in the upper trapezius muscle during light manual work. Ergonomics 50, 161–177.

Burnett, A., Green, J., Netto, K., Rodrigues, J., 2007. Examination of EMG normalisation methods for the study of the posterior and posterolateral neck muscles in healthy controls. Journal of Electromyography and Kinesiology 17, 635–641.

Cailliet, R., 1981. Neck and Arm Pain. FA Davis.

Chaffin, D.B., Andersson, G., Martin, B.J., 1991. Occupational Biomechanics. Wiley, New York.

Chee, H.L., Rampal, K.G., 2004. Work-related musculoskeletal problems among women workers in the semiconductor industry in Peninsular Malaysia. International Journal of Occupational and Environmental Health 10, 63–71.

Côté, P., van der Velde, G., David Cassidy, J., Carroll, L.J., Hogg-Johnson, S., Holm, L.W., Carragee, E.J., Haldeman, S., Nordin, M., Hurwitz, E.L., 2008. The burden and determinants of neck pain in workers. European Spine Journal 17, 60–74.

Dahlberg, R., Karlqvist, L., Bildt, C., Nykvist, K., 2004. Do work technique and musculoskeletal symptoms differ between men and women performing the same type of work tasks? Applied Ergonomics 35, 521–529.

Dunning, K.K., Davis, K.G., Cook, C., Kotowski, S.E., Hamrick, C., Jewell, G., Lockey, J., 2010. Costs by industry and diagnosis among musculoskeletal claims in a state workers compensation system: 1999–2004. American Journal of Industrial Medicine 53, 276–284.

Fejer, R., Kyvik, K.O., Hartvigsen, J., 2006. The prevalence of neck pain in the world population: a systematic critical review of the literature. European Spine Journal 15, 834–848.

Hagberg, M., 1984. Occupational musculoskeletal stress and disorders of the neck and shoulder: a review of possible pathophysiology. International Archives of Occupational and Environmental Health 53, 269–278.

Hagberg, M., Wegman, D., 1987. Prevalence rates and odds ratios of shoulder–neck diseases in different occupational groups. British Medical Journal 44, 602.

Hales, T.R., Bernard, B.P., 1996. Epidemiology of work-related musculoskeletal disorders. Journal of Orthopedic Clinic of North America 27, 679–709.

Hogg-Johnson, S., Van Der Velde, G., Carroll, L.J., Holm, L.W., Cassidy, J.D., Guzman, J., Côté, P., Haldeman, S., Ammendolia, C., Carragee, E., 2008. The burden and determinants of neck pain in the general population. European Spine Journal 17, 39–51.

Jeffreys, E., 1993. Applied Anatomy. Disorders of the Cervical Spine, second ed. Butterworths, London, pp. 1–18.

Jensen, B.R., Schibye, B., Søgaard, K., Simonsen, E.B., Sjøgaard, G., 1993. Shoulder muscle load and muscle fatigue among industrial sewing-machine operators. European Journal of Applied Physiology and Occupational Physiology 67, 467–475.

Kee, D., 2005. Gender differences in rankings of joint motion stressfulness based on psychophysical scaling. International Journal of Industrial Ergonomics 35, 461–469.

Larsson, B., Søgaard, K., Rosendal, L., 2007. Work related neck–shoulder pain: a review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. Best Practice & Research Clinical Rheumatology 21, 447–463.

Larsson, S.E., Bodegård, L., Henriksson, K., Öberg, P.Å., 1990. Chronic trapezius myalgia: morphology and blood flowlstudied in 17 patients. Acta Orthopaedica 61, 394–398.

Lipscomb, J., Trinkoff, A., Brady, B., Geiger-Brown, J., 2004. Health care system changes and reported musculoskeletal disorders among registered nurses. American Public Health Association, 1431–1435.

Malchaire, J., Cock, N., Vergracht, S., 2001. Review of the factors associated with musculoskeletal problems in epidemiological studies. International Archives of Occupational and Environmental Health 74, 79–90.

National Research Council, 2001. Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. National Academy Press, Washington, DC.

Nimbarte, A.D., Aghazadeh, F., Ikuma, L.H., Harvey, C.M., 2010. Neck disorders among construction workers: understanding the physical loads on the cervical spine during static lifting tasks. Industrial Health 48, 145–153.

Nimbarte, A.D., Aghazadeh, F., Ikuma, L.H., Sun, Y., 2011. Evaluation of overhead pushing and pulling exertions on the loading of neck and shoulder musculature. Human Factors and Ergonomics in Manufacturing & Service Industries 22, 317–327.

Nimbarte, A.D., Al Hassan, M.J., Guffey, S.E., Myers, W.R., 2012. Influence of psychosocial stress and personality type on the biomechanical loading of neck and shoulder muscles. International Journal of Industrial Ergonomics 42, 397–405.

O'Sullivan, L., Gallwey, T., 2002. Effects of gender and reach distance on risks of musculoskeletal injuries in an assembly task. International Journal of Industrial Ergonomics 29, 61–71.

Punnett, L., Wegman, D.H., 2004. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. Journal of Electromyography and Kinesiology 14, 13–23.

Rosecrance, J., Rodgers, G., Merlino, L., 2006. Low back pain and musculoskeletal symptoms among Kansas farmers. American Journal of Industrial Medicine 49, 547–556.

Silverstein, B., Viikari-Juntura, E., Kalat, J., 2002. Use of a prevention index to identify industries at high risk for work-related musculoskeletal disorders of the neck, back, and upper extremity in Washington state, 1990–1998. American Journal of Industrial Medicine 41, 149–169.

Sommerich, C.M., Joines, S.M., Hermans, V., Moon, S.D., 2000. Use of surface electromyography to estimate neck muscle activity. Journal of Electromyography and Kinesiology 10, 377–398.

Straker, L.M., Smith, A.J., Bear, N., O'Sullivan, P.B., de Klerk, N.H., 2011. Neck/shoulder pain, habitual spinal posture and computer use in adolescents: the importance of gender. Ergonomics 54, 539–546.

Trinkoff, A., Brady, B., Nielsen, K., 2003. Workplace prevention and musculoskeletal injuries in nurses. JONA: The Journal of Nursing Administration 33, 153–158.

Turville, K., Psihogios, J., Ulmer, T., Mirka, G., 1998. The effects of video display terminal height on the operator: a comparison of the 15 and 40 recommendations. Applied Ergonomics 29, 239–246.

Villanueva, M., Jonai, H., Sotoyama, M., Hisanaga, N., Takeuchi, Y., Saito, S., 1997. Sitting posture and neck and shoulder muscle activities at different screen height settings of the visual display terminal. Industrial Health 35, 330–336.

Walker-Bone, K., Cooper, C., 2005. Hard work never hurt anyone: or did it? A review of occupational associations with soft tissue musculoskeletal disorders of the neck and upper limb. Annals of the Rheumatic Diseases 64, 1391–1396.

Widanarko, B., Legg, S., Stevenson, M., Devereux, J., Eng, A., Mannetje, A., Cheng, S., Douwes, J., Ellison-Loschmann, L., McLean, D., 2011. Prevalence of musculoskeletal symptoms in relation to gender, age, and occupational/industrial group. International Journal of Industrial Ergonomics.