International Journal of Industrial Ergonomics 42 (2012) 397–405

Contents lists available at SciVerse ScienceDirect

International Journal of Industrial Ergonomics

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

Influence of psychosocial stress and personality type on the biomechanical loading of neck and shoulder muscles

Ashish D. Nimbarte*, Mohammed J. Al Hassan, Steve E. Guffey, Warren R. Myers

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

ARTICLE INFO

Article history:
Received 25 August 2011
Received in revised form
10 April 2012
Accepted 7 May 2012
Available online 7 June 2012

Keywords:
Musculoskeletal disorders
Personality
Psychosocial stress
Neck
Shoulder
Electromyography
NASA-TLX

ABSTRACT

The purpose of this study was to explore the influence of individual personality on the biomechanical response of neck and shoulder muscles to physical and psychosocial demands. Eighteen healthy male participants performed isometric pulling exertions in a semi-standing posture in the presence and absence of mentally demanding tasks. Surface electromyography (EMG) was used to quantify biomechanical response of neck and shoulder muscles, and the NASA Task Load Index (TLX) was used for subjective workload assessment. The effect of individual personality as a potential modifier was evaluated by classifying participants into thinking and feeling personality types. Mentally demanding tasks performed prior to the physical exertions significantly affected the muscle loading during the physical exertion. Activation of the shoulder as well as neck muscles increased with the addition of mental stress. Higher workload scores for mental and temporal demands, and frustration were reported by the participants during combined physical and mental tasks. In general, participants with feeling personality showed higher increase in the muscle activation level than participants with thinking personality corresponding to identical mental and physical demands, which indicate that response to mental stress during physically demanding tasks seems to be mediated by the individual personality.

Relevance to industry: Work environments in modern work places, with strong emphasis on efficiency, competitiveness, and downsizing, are characterized by a combination of physical and psychosocial demands. Individual factors such as personality traits are known to interact with these work-related factors to reconcile or aggravate the body's biomechanical response, yet the interacting effect of these factors on muscular loading is not clearly understood. The results of this study indicate that certain personalities are more vulnerable than others to increased muscle loading in response to mental stress during physically demanding tasks.

1. Introduction

The overall burden of work-related musculoskeletal disorders (MSD) and complaints in terms of health and economics is enormous in many industrialized countries. For a long time, low back pain has been the leading problem. In recent years, pain in the shoulder and neck region seems to occur more frequently. In recent studies by the U.S. Bureau of Labor Statistics, it was reported that injuries to the neck and shoulder region cause a median of 21 days away from work compared to seven days for injuries to the low back (BLS, 2011). An annual prevalence of 30%–50% for neck pain among the general adult population was reported by the Bone and Joint Decade on Neck Pain Task Force (Hogg-Johnson et al., 2008). Among the working population, nearly 11%–14.1% of workers were found to suffer from disabling neck pain symptoms, i.e., they are limited in their activities because of neck pain (Côté et al., 2008). Although symptoms of neck pain vary considerably across occupations and populations, prevalence of neck pain was greater for individuals who are frequently exposed to physical demands and psychosocial stress in the workplace. Working conditions in the healthcare environment require exposure to the combined physical and psychosocial demands. In the recent years, although the incidence rate of nonfatal occupational injuries and illnesses requiring days away from work has decreased in most of the occupations, it had increased among the healthcare workers (BLS, 2011). Low back being the most frequently injured body part, MSD of neck and shoulder significantly contribute to morbidity among the healthcare workers. As a matter of fact, few studies have reported a higher rate of neck and shoulder MSD than the low

* Corresponding author. Tel.: +1 304 293 9473; fax: +1 304 293 4970.
E-mail addresses: Ashish.Nimbarte@mail.wvu.edu (A.D. Nimbarte), malhassa@mix.wvu.edu (M.J. Al Hassan), Steve.Guffey@mail.wvu.edu (S.E. Guffey), Warren.Myers@mail.wvu.edu (W.R. Myers).

0169-8141/$ – see front matter
doi:10.1016/j.ergon.2012.05.001

back MSD among healthcare workers (Trinkoff et al., 2002; Smith et al., 2006).

Different types of physical exertion are deemed to be the causal factors of work-related neck pain in the epidemiological studies. Exertions demanding low levels of prolonged and/or repetitive movement lie on one end of spectrum (Kaergaard and Andersen, 2000; Johnston et al., 2008; Korhonen et al., 2003; Jensen et al., 2002; Morse et al., 2007; Sivak-Callcott et al., 2011). Whereas forceful arm exertions required in physically demanding activities lie on the other end of the spectrum (Aublet-Cuvelier et al., 2006; Chee and Rampal, 2004; Lipscomb et al., 2004; Rosecrance et al., 2006; Silverstein et al., 2002; Trinkoff et al., 2003). Low levels of sustained exertion were typically associated with inflammatory-type neck pain syndromes such as trapezius myalgia, cervicalgia, etc. (Juul-Kristensen et al., 2006). Over-activation of low-threshold motor units (Cinderella) is the most commonly used mechanism to study the pathogenesis of such types of neck pain syndromes (Nordander et al., 2004; Forsman et al., 1999). Heavy exertions, on the other hand, are identified as the risk factors for muscle-specific disorders, such as tension neck syndrome, and disc specific diseases, such as herniated/protruded discs. In the healthcare setting, with the advent of mechanical patient transfer devices, lifting exertions have been reduced to a great extent; however, pushing and pulling exertions during routine patient handling tasks, are still regularly performed by the workers (Koppelaar et al., 2012). Some of the patho-mechanisms commonly used by researchers to study neck pain disorders associated with forceful arm exertions include: ruptured z-discs of muscle leading to the production of metabolites (Hagberg, 1984); reduced blood flow (Larsson et al., 1990); increased friction between the tendon and adjacent surfaces due to the uniaxial tensile forces generated by muscles (Radwin and Lavender, 1999; Ashton-Miller, 1999); and excessive forces acting on the cervical discs (Nimbarte et al., 2010a).

In addition to physical demands, healthcare workers are frequently exposed to other work-related factors such as mental demand, administrative hassles, time pressure, lack of social support, conflicting demands, lack of control over job pace, etc. (Iizuka et al., 2012; Hoe et al., 2012). These factors, typically known as psychosocial or psychological factors, draw on the mental reserve of the workers and cause cognitive dissonance (Bloemsaat et al., 2005; Davis et al., 2002). Epidemiological studies identify these factors in combination with physical exertion as the risk factors for neck pain (Walker-Bone and Cooper, 2005; Malchaire et al., 2001; Ariens et al., 2000). Cognitive dissonance caused by increased mental stress is believed to amplify the biomechanical response of the musculoskeletal system to physical factors (Davis et al., 2002; Marras et al., 2000). For tasks with low levels of physical exertion, the effect of concurrent mental tasks on the behavior of upper extremity muscles has been investigated in a number of studies (Bloemsaat et al., 2005; Birch et al., 2000; Laursen et al., 2002; Lundberg et al., 2002, 1994). During such exertions, it was found that the low-threshold motor units fire continuously during physical as well as mental exertion, and, thus can be at a higher risk of getting overloaded and damaged. In the case of heavy exertion, studies evaluating the effect of concurrent mental demands on the biomechanical response of the musculoskeletal system during physical exertion are sparse and report contradictory findings. MacDonell and Keir (2005) found that shoulder moment and muscle activities during 30% grip exertion at various flexion and abduction angles decreased with the addition of mental strain. Au and Keir (2007) found that, during tasks requiring 30% of grip and 40% shoulder exertion, with the addition of mental tasks, increased the trapezius muscle activity but decreased the deltoid muscle activity. Recently, Mehta and Agnew (2011) found that during upper extremity exertion performed at 5%, 25%, 45%, 65%, and 85% MVC, the addition of mental tasks resulted in decreased upper and lower arm muscle activity. Studies evaluating low-back loading during a combination of physical and mental exertion, on the other hand, consistently found that simultaneous mental processing during lifting tasks increase trunk muscle co-activation, further increasing the shear and compressive loading of the lumbar spine (Davis et al., 2002; Marras et al., 2000).

The interactive relationship between the aforementioned work-related factors and the biomechanical response of the musculoskeletal system is further complicated by individual factors. In a conceptual model developed by the National Academy of Science that identifies a relationship between the various risk factors for work-related low-back pain, individual factors such as personality, size, strength, and perception were mentioned to either reconcile or intensify the effect of workplace factors on the biomechanical response (National Academy of Science, 2001). A number of studies have also identified individual factors as important parameters in the development of neck-shoulder MSD (Sommerich et al., 1993; Hughes et al., 2007; Lagerström et al., 1996). Among the individual factors, personality traits were found to be sensitive to the relationship between the external work-related factors and internal musculoskeletal loading. Allread and Marras (2006) reported that participants whose personality traits were not matched with the requirements of their work showed signs of increased MSD and discomfort compared to those whose personality preferences better matched their job. Glasscock et al. (1999) found that participants with certain personality types showed higher muscle co-activation for the flexor and extensor muscles during elbow flexion tasks. Individual personality was also found to influence co-contraction of the trunk muscles caused by the combination of physical and psychosocial exertion, further affecting the compression and shear loading of the lumbar spine during lifting exertions (Davis et al., 2002; Marras et al., 2000).

In view of the fact that work-related neck pain has multidimensional etiologies with physical work demand, psychosocial factors, and individual factors contributing significantly to the cause of the disorder, only a few studies have explored the interaction between these factors. Therefore, the objective of this study was to explore how the interaction of specific psychosocial factors (mental demand) and individual factors (personality trait) might affect the variables that influence loading of the neck and shoulder musculatures caused by physical exertion. To study this interrelationship, tasks specific to the healthcare setting were selected. The rationale for selecting healthcare specific tasks was the high prevalence of neck pain among healthcare workers and the relatively complex nature of their jobs, which routinely expose them to physical and psychosocial stress. It was hypothesized that mental demand, in addition to physical demand, would lead to an increase in loading of neck and shoulder musculatures. Furthermore, it was also hypothesized that the relationship between the external work-related factors and the internal loading of neck-shoulder muscles will be inconsistent between the different personality types, implying that personality type plays an important role in the MSD development pathway.

2. Material and methods

2.1. Approach

A lab-based study was performed to investigate the impact of work-related physical and psychosocial factors, and personality traits on the activities of neck and shoulder muscles using electromyography (EMG). In addition NASA-Task Load Index (TLX) workload scores were used to quantify the subjective workload which was used as a measure of psychosocial stress. The physical task in this study involved force exertion during bed-to-stretcher patient transfer. Similar type of bed-to-stretcher patient transfer task was previously studied to quantify the effect of healthcare related physical exertions on the biomechanical loading of upper extremities and low back (Owen, 2000). Based on Rasmussen's categories of human performance (Rasmussen, 1983), skill-based tasks were used to generate mental demands. Skill-based tasks rely on rote knowledge and fairly automatic responses with minimal signal processing, such as memorizing and recalling a list of words, performing arithmetic calculations, etc. Healthcare workers perform various skill-based tasks in daily work activities, such as remembering patients' medications, recalling physical therapy schedules, and checking vital signs.

2.2. Participants

A total of eighteen participants were recruited for data collection in this study. The average age, weight, and height of the participants were 24 ± 2.5 yrs, 168.6 ± 24.8 lb, and 178 ± 9.8 cm, respectively. 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). Before data collection, the experimental procedures and possible risks associated with the study were explained to the participants, and their signatures were obtained on the consent form approved by the local Institutional Review Board.

2.3. Experimental design

A two-factor mixed experimental design with one within-subject variable and one between-subject variable was used. The within-subject variable, type of exertion, was treated at two fixed levels (physical only and a combination of physical and mental), and the between-subject variable, individual personality, was also treated at two levels (thinking and feeling). Individual personality type was determined using the Myers Briggs Type Indicator (MBTI) test, which has been previously used by Davis et al. (2002) and Marras et al. (2000) to study the effect of personality traits on low-back loading. This test uses four factors to identify different types of personalities. These factors are "favorite world" (Extraversion vs. Introversion), "information processing preference" (Sensing vs. Intuition), "decision making" (Thinking vs. Feeling), and "structure" (Judging vs. Perceiving). Based on each factor, the classification of personality is binary, i.e., an individual can be classified into either of the two personality types. If all four factors are combined, then sixteen different personalities can be evaluated. Since the work of healthcare workers often demands decision making (Hammer, 1993), the participants were classified into two personality types: thinking and feeling.

2.4. Apparatus

2.4.1. Telemyo 2400 EMG system

This is a 16-channel telemetry EMG system consisting of a Telemyo 2400T transmitter, pre-amplified lead wires, and disposable, self-adhesive Ag/AgCl snap electrodes (Noraxon Inc., AZ, USA). The bipolar Ag/AgCl pre-gelled surface electrodes (1 cm diameter, inter-electrode distance is 2 cm) connect to the Telemyo 2400T transmitter via pre-amplified lead wires. The pre-amplifier on the lead wires have a band-pass of 10–1000 Hz (gain 500), CMRR >100 dB, Input Impedance >100 MΩ. The Telemyo 2400 transmitter sends the data to the host computer over a wireless network. The frequency of EMG data acquisition was set at 1500 Hz.

2.4.2. Custom-built strength testing device

To simulate force exertion during bed-to-stretcher patient transfer a custom-built strength testing device was used. This device consists of a 6-inch wide slotted steel plate, chain, series 5 advanced digital force gauge (Mark-10 Corporation, NY, USA), and a pair of sheets (Fig. 1). The chain attaches the force gauge to the steel plate such that the force gauge can move up and down along the plate and can be locked at any position. The force gauge was attached to the pair of cloth sheets using a double-handle attachment. Cloth sheets were used during the force exertion to make the simulated patient transfer task more realistic (Fig. 2). The series 5 advanced digital force gauge is designed to measure tension and compression forces with an accuracy of ±0.1% of full scale and a resolution of 1/5000.

2.5. Data collection procedure

The data collection procedures for each participant consisted of the following three steps.

2.5.1. Subject orientation and measurement

Each participant was introduced to the equipment, data collection procedures, and specifics of the experimental tasks. Demographics and anthropometric measurements were recorded. Subsequently, each participant's personality type was identified using the MBTI test.

Fig. 1. Picture of custom-built isometric pulling strength testing device used in this study to induce physical demand.

2.5.2. EMG data collection preparation

The skin underneath the anatomical landmarks was shaved (if needed), abraded, and cleaned with 70% alcohol, prior to the placement of the EMG electrodes. EMG from the sternocleidomastoid muscle was recorded by placing an electrode along a line drawn from the sternal notch to the mastoid process, at 1/3 the length of the line from the mastoid process (Nimbarte et al., 2010b). EMG from the cervical trapezius muscle was measured by placing an electrode between the occipital and 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-C7 vertebrae above the C7. The electrode at this location was placed slightly inclined (approximately 35°) to the vertical line between the C7 and C4 (Nimbarte et al., 2010b). EMG from the upper trapezius muscle in the shoulder region was recorded by placing an electrode along a line joining the acromion and C7, at one-third the distance from the acromion, in accordance with the published recommendations (Farina et al., 2002).

2.5.3. Actual data collection

Each subject participated in two experimental sessions. Session 1 consisted of tasks that impose physical demands. The participant performed 10 maximal isometric pulling exertions simulating force exertion during a bed-to-stretcher patient transfer task. During the pulling task, the height of the force gauge and double-handle attachment was adjusted to 66 cm above the ground level to make it consistent with the average height of beds used in hospitals (Tzeng and Yin, 2006). During the force exertion, the participant stood at a distance of 50 cm from the column and exerted force using a posture characterized by following joint configuration:

1. Knee joint flexed 5–10°.
2. Trunk flexion of 10–20°.
3. Right foot placed in front of the left foot with an approximate distance of 30–35 cm between the feet (anterior–posterior)
4. Shoulder joint flexed 50–55° and 0° abducted.
5. Elbow joint flexed 5–10° and 50–55° supinated.
6. Wrist in the neutral posture.

A picture of a participant performing the pulling task is shown in Fig. 2. During the pulling exertion, the participant was instructed to apply the force slowly and steadily without a jerking motion until the maximum exertion was reached (Aghazadeh and Ayoub, 1985). The maximum exertion was maintained for approximately 3–5 s. After each exertion, participant rated the perceived workload using the NASA-TLX. A rest of 35–45 s was provided before the next pulling exertion. The total duration of session 1 was 10 min.

Session 2 consisted of tasks that impose a combination of physical and mental demands. In addition to 10 isometric pulling exertions (same as Session 1), the participants performed tasks that induced mental demand during the rest period following each pulling exertion, thereby providing a constant mental load. Participants were presented with a list consisting of names of diseases, symptoms, and prescription drugs to remember. Immediately following the pulling exertion, participants were verbally asked questions related to the information presented in the previous rest period and allowed 10 s to verbally answer the question. In addition, the participant performed three arithmetic calculations. The participant then rated the perceived workload using the NASA-TLX. A rest period of up to 5 s was provided before the next mental task was performed. The division of tasks and the corresponding time allotment during the two sessions is shown in Fig. 3.

Fig. 2. A participant fitted with EMG surface electrodes performing isometric pulling task using the custom-built strength testing device.

2.6. Data processing and analysis

EMG data were processed to calculate mean absolute values (MAV). The steps involved in the calculation of MAV consist of: 1) demeaning the EMG signal, 2) performing a full wave rectification, 3) filtering the data to suppress high frequency fluctuation using a low-pass Butterworth filter (Fourth order, zero lag filter, cutoff frequency of four), and 4) averaging the filtered data which is the MAV (Nimbarte et al., 2010b). The MAV data was normalized with respect to the reference contraction to determine the Normalized MAV (N-MAV (%RVE)) (Sommerich et al., 2001; Finsen, 1999).

NASA-TLX data were processed to calculate weighted ratings for each subscale. To obtain weighted ratings, the raw rating for each subscale in the NASA-TLX were multiplied by its weight, i.e., the contribution of each subscale to the workload. Previous studies have indicated that obtaining weights at the end of each sub-task can increase sensitivity of the derived workload scores only slightly and did not warrant the additional time required to gather them. Therefore, weights were obtained at the end of each session. The averages of the raw ratings at the end of each experimental session for different subscales were multiplied by the corresponding weights to calculate the weighted rating. The weighted ratings were used as dependent variables for further analysis.

2.7. Statistical analysis

Twelve dependent variables were evaluated in this study: (1) (2) NMAV of right and left sternocleidomastoid muscle; (3) (4) NMAV of right and left cervical trapezius muscle; (5) (6) NMAV of right and left upper trapezius muscle; (7) to (12) weighted rating for six NASA-TLX workload subscales. Normality of the data was tested

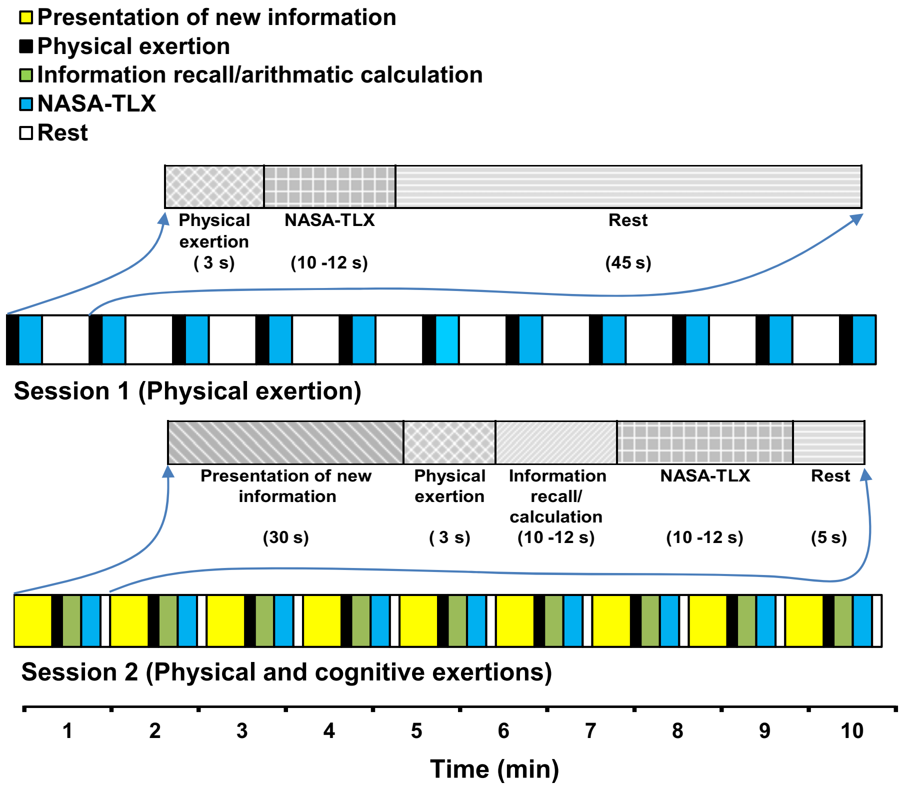

Fig. 3. The task division and corresponding time allotment during the two sessions.

using the Kolmogorov–Smirnov test and all dependent variables found to be normally distributed. A two-way mixed model analysis of variance (ANOVA) was used to investigate the main effects of type of exertion and personality, and any interaction effect. A mixed model allowed for fixed effects as well as random effects. Fixed effects were type of exertion and personality type. The random effect was subject. Significance level was set to 95%. All analyses were performed using Minitab statistical software (Minitab Inc., State College, PA).

3. Results

The demographic data and the personality type of the 18 participants in this study are shown in Table 1. The average of maximum forces exerted by the participants during session 1 (physical only) and session 2 (combination of physical and cognitive) were 266.5 N (85.8) and 293.1 N (92.1), respectively.

3.1. Muscle activity

The activities of upper trapezius muscles were significantly affected by the type of exertion ($P < 0.001$) (Table 2). The effect of personality type was statistically not significant; however, a general trend showed a higher increase in muscle activity for participants with feeling personality than thinking personality. The interaction effect of the type of exertion and the personality type was statistically significant for the upper trapezius muscles on left side. For the participants with thinking personality, with the addition of mental demands, on an average, the muscle activity increased by 52.2% and 41.0% for the right and left side, respectively (Fig. 4(a)). The corresponding values for the participants with feeling personality were 70.8% and 68.7%, respectively.

For the sternocleidomastoid and cervical trapezius muscles, the effect of type of exertion was statistically significant (all $P < 0.001$). Participants with feeling personality have shown higher activation for these muscles than thinking personality. The effect of

Table 1
Characteristics of study subjects.

	Subject	Gender		Age	Weight (lb)	Height (cm)	Personality type	
		Male	Female				Thinking	Feeling
Number	18	16	2				9	9
Mean				25	162.4	173		
SD				2.5	22.1	9.7		

Table 2
Main effect of type of exertion and personality type on the normalized activity (% RVE) of neck and shoulder muscles.

Muscle	Side	Type of exertion		*P*-value
		Session 1	Session 2	
Upper Trapezius	Right	71.9(17.7)	115(39.3)	**<0.001**
	Left	68.0(22.0)	107(38.2)	**<0.001**
Sternocledomastoid	Right	75.7(18.1)	120(62.2)	**<0.001**
	Left	74.8(17.3)	119(66.3)	**<0.001**
Cervical Trapezius	Right	78.7(15.4)	108(33.7)	**<0.001**
	Left	78.1(14.9)	113(35.3)	**<0.001**
		Personality type		
		Thinking	Feeling	
Upper Trapezius	Right	97.9(38.1)	89.8(36.6)	0.230
	Left	82.5(33.5)	92.8(39.2)	0.233
Sternocledomastoid	Right	90.5(32.1)	105.3(63.6)	0.241
	Left	83.0(42.8)	111.5(58.9)	**0.024**
Cervical Trapezius	Right	85.3(24.6)	101.5(32.7)	**0.027**
	Left	90.0(29.5)	102.0(34.2)	0.099

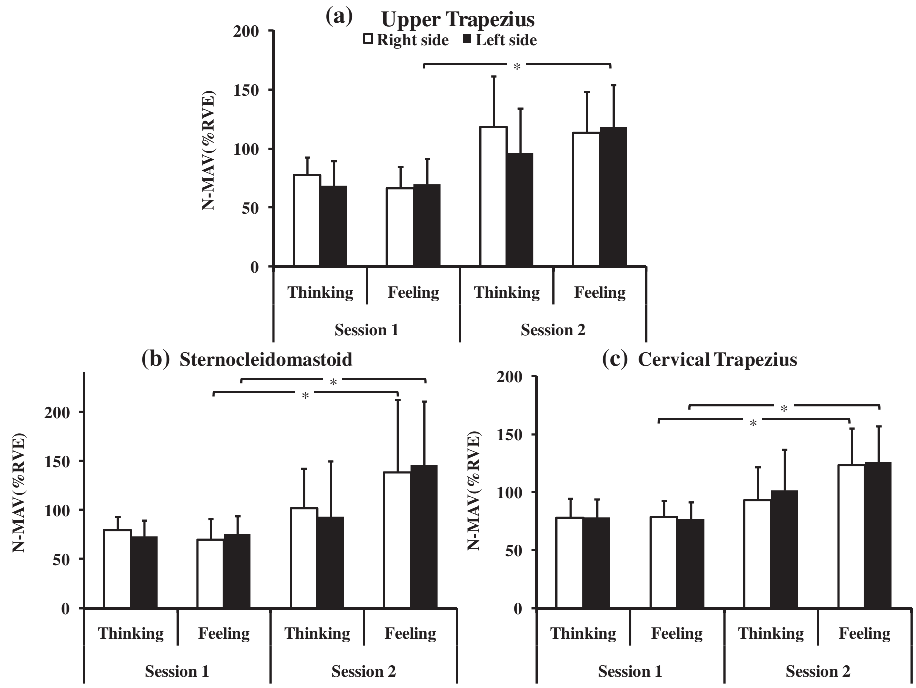

Fig. 4. Bar charts showing increase in the mean normalized muscle activity of neck and shoulder muscles with the addition of cognitive load during session 2 for the participants with different personalities. Columns marked with bracket and * are significantly different from each other. Error bars represent one standard deviation.

personality was statistically significant for sternocleidomastoid muscle on the left side and cervical trapezius muscle on the right side (Table 2). A significant interaction between the type of exertion and the personality type was observed for both these muscles (all $P < 0.001$) (Fig. 4(b) and (c)). Addition of mental demands increased the activity of sternocleidomastoid muscle on left and right side by 28.8% and 28.5%, respectively, for the participants with thinking personality. For the participants with feeling personality, the corresponding values were 97.9% and 93.2%, respectively. For cervical trapezius muscle, an increased activation of 19.3% and 29.9% was observed for the right and left side, respectively, with the addition of mental demand, for the participants with thinking personalities. For the participants with feeling personality the corresponding values were 57.3% and 64.2%, respectively.

3.2. NASA-TLX

The weighted ratings for all the NASA-TLX subscales, except efforts, were significantly affected by the type of exertion (all $P < 0.001$) (Table 3). The addition of a mental task increased the weighted ratings for mental demand, temporal demand, and frustration by 91.4%, 32.9%, and 45.1%, respectively. Whereas, during physical exertions alone, weighted ratings for the physical demand and performance were 36.1% and 15.8% greater than the combination of physical and mental exertions, respectively. The main effect of personality and interaction between type of exertion and personality was statistically not significant for the weighted ratings of any of the NASA-TLX subscales (Fig. 5).

4. Discussions

This study investigated the effect of individual personality traits on the interactive effect of work-related physical and psychosocial exertions on the activity of neck and shoulder muscles and subjective workload. Addition of psychosocial demand, in terms of memory tasks, increased the muscle activity and overall subjective workload. Individual personality traits were found to have a modifying effect on this relationship. Thus, this study for the first time provides an indication that individual personality traits play an important role in the biomechanical loading of the upper extremities.

Mentally demanding tasks performed prior and subsequent to heavy physical exertion significantly increased the activity of the upper trapezius, sternocleidomastoid, and cervical trapezius muscles during the physical exertion. A similar effect of concurrent mental demand on the upper trapezius muscle was previously reported in a number of studies that examine the effect of low levels of force exertions (Bloemsaat et al., 2005; Birch et al., 2000; Laursen et al., 2002; Lundberg et al., 2002, 1994). Studies evaluating relatively higher levels of force exertion (up to 40% MVC) by wrist and

Table 3
Main effect of type of exertion and personality type on the weighted ratings of NASA-TLX subscales.

NASA-TLX subscales	Type of exertion		*P*-value
	Session 1	Session 2	
Mental demand	6.5(3.9)	82.7(17.4)	**<0.001**
Physical demand	61.3(18.8)	37.4(13.0)	**<0.001**
Temporal demand	29.2(14.6)	42.7(22.6)	**0.057**
Performance	27.6(10.7)	21.9(6.4)	**0.041**
Effort	35.0(14.9)	34.0(27.1)	0.929
Frustration	20.7(14.8)	37.2(16.9)	**0.001**
	Personality type		*P*-value
	Thinking	Feeling	
Mental demand	42.5(39.1)	47.3(43.5)	0.253
Physical demand	48.5(15.9)	50.4(24.8)	0.760
Temporal demand	41.3(22.9)	29.3(13.3)	0.065
Performance	25.8(10.6)	23.3(7.0)	0.486
Effort	34.0(19.9)	35.1(24.1)	0.894
Frustration	29.7(19.8)	28.0(15.3)	0.807

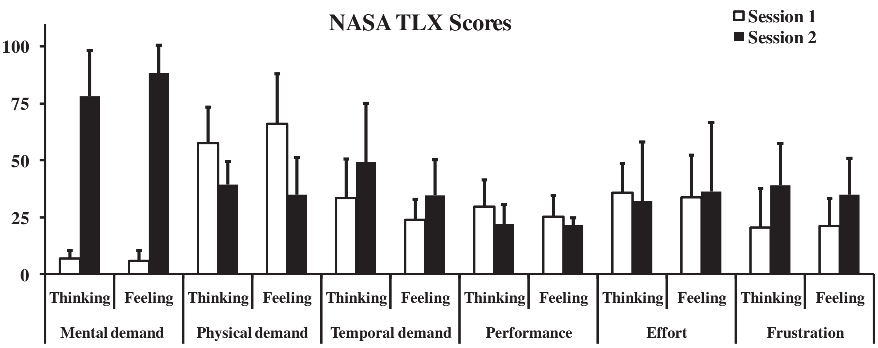

Fig. 5. Average weighted ratings for different NASA-TLX subscales as a function of sessions (type of exertion) and personality type.

shoulder joints report inconsistent trends for concurrent mental and physical demands on the behavior of the upper trapezius muscle (MacDonell and Keir, 2005; Au and Keir, 2007; Mehta and Agnew, 2011). A direct comparison of the findings of the present study with aforesaid previous studies is difficult due to differences in a number of experimental design variables. In addition to the force exertion levels and overall nature of the tasks, the spacing of the tasks used in this study was fundamentally different from the previous studies. In this study, mentally demanding tasks were performed prior and subsequent to the physical exertions, and not simultaneously with the physical exertions. The exact pathophysiology relating the cognitive stress and increased muscle activation is unknown; however, some authors have theorized increased muscle stiffness or joint tightness as a plausible explanation for this observation. Bloemsaat et al. (2005) stated that mental processing increases the neuromotor noise at the muscle level and adjusting (increasing) muscle stiffness is a filtering strategy used by the muscle to attenuate this enhanced noise. An alternative explanation is the presence of a mechanism that controls available biomechanical degrees of freedom to increase accuracy of task performance with increased mental processing during physical exertion. van Loon et al. (2001) provided experimental evidence supporting a reduction in the available biomechanical degrees of freedom during complex physical and mental tasks to improve accuracy. They found that during a combined weight lifting and arithmetic task the elbows were positioned closer to the body in a mental-stress condition. Closer positioning of the elbow joints reduces the available biomechanical degrees of freedom by tightening the joint and increasing co-contraction of the surrounding musculature. With regard to these theories, we believe that during session 2, increased muscle stiffness or neck-shoulder joint tightness caused by the cognitive dissonance due to the mental stressors may have sustained during the physical exertion, causing an augmented increase in the muscle activation level.

Addition of a mental stressor showed a steady effect on activity of the neck and shoulder muscles. In general, with the addition of mental demand, the muscle activation during physical exertions increased by 57%, 61%, and 43%, for upper trapezius, sternocleidomastoid, and cervical trapezius muscles, respectively. The upper trapezius muscle is a major shoulder muscle, and as noted above, its susceptibility to mental demands is well documented in previous studies. The findings of this study indicate that, in addition to the upper trapezius muscles, behavior of muscles in the neck region, sternocleidomastoid, and cervical trapezius were also vulnerable to mental stress. Compared to the upper trapezius muscle, the sternocleidomastoid and cervical trapezius muscles are relatively smaller. Based on the neuromotor noise theory, it is believed that larger muscles are better suited to deal with increased neuromotor noise following increased mental processing than smaller muscles. This notion was found to be true for exertions with low levels of force demands and is being supported by the experimental data provided by Waersted and Westgaard (1996) and Bloemsaat et al. (2005). However, results of the present study show that during heavy exertions, independent of muscle size, mental demands increase the muscle activation level to almost similar levels. Perhaps the three muscles studied in this paper, despite their cross-sectional area, control equal number of biomechanical degrees of freedom during the pulling task used in the study. This may have led to similar levels of increased co-contraction causing identical levels of increased muscle activation. Owing to this explanation, it seems that reduction in the available biomechanical degrees of freedom theory provides better justification for the increased muscle activation during concurrent heavy physical demand and mental strain.

The results of the present study suggest that personality trait may be responsible for differences in the biomechanical loading of the neck and shoulder muscles due to mental stress. Participants with feeling personality type demonstrated a higher activation level than thinking personality type. Based on the neuromotor noise and biomechanical degrees of freedom theory, it is believed that an individual's ability to respond to mental strain without adversely affecting muscle stiffness or joint tightness may depend on their personality. In one study, asymptomatic workers, because of their ability to keep muscles relaxed, were claimed to develop significantly lower muscle loading than symptomatic workers in response to similar levels of work-related psychosocial stress (Lundberg et al., 1999). Perhaps the participants with the thinking personality in this study were able to keep their muscles relatively more relaxed than the feeling personality, and therefore, showed a comparatively lower increase in muscle activities with the addition of mental demand. Overall, the results of this study provide experimental evidence which seems to indicate that individual personality trait is one of the key factors in the array of multidimensional etiologies that influence neck-shoulder MSD. Further, the results imply that studies viewing the entire work system (the interaction of physical and psychosocial workplace issues, as well as individual factors) by implementing multi-factorial approaches will most likely derive the root causes of neck-shoulder MSD.

Addition of mental tasks resulted in higher NASA-TLX workload scores for mental and temporal demands. A higher frustration was also reported by the participants during combined physical and mental tasks. This is a clear indication that the protocol used in this study successfully generated psychosocial stress. Higher workload scores for physical demand during physical tasks than combined physical and mental tasks were found, in spite of identical force exertion levels and longer rest periods during physical tasks. This may be a result of relatively higher weights given by the participants to the physical demand during physical tasks. Between the two types of tasks, although participants perceived similar raw workload ratings for physical demand during these tasks, they perceived higher weights for physical demand during the physical task than combined physical and mental tasks. Surprisingly, no significant trends in the subjective workload assessment scores with respect to personality trait were noted in this study. This may be partly because the NASA TLX tool assesses the workload on a global (whole body) level, and although it was designed for evaluating tasks that require mental processing, its higher sensitivity to tasks with combined physical and mental demand has been emphasized in previous studies (Mehta and Agnew, 2011; DiDomenico and Nussbaum, 2008). The physical task investigated in this study primarily required contribution from the upper extremity musculature. It is likely that while reporting subjective workload, participants may have considered the overall physical demand and not explicitly the demand on the neck and shoulder musculature. We believe that a local perceived discomfort assessment method similar to Borg CR-10, designed especially for the neck and shoulder region, may have provided a better understanding of a relationship between subjective assessment outcomes and personality traits.

Several potential limitations need to be considered when the results of this study are interpreted. Psychosocial stress was manipulated using memory tasks. Although this is one way of generating stress, other methods such as uncooperative behavior, time pressure, etc., could also be used. It is likely that different aspects of psychosocial stress may affect the interactive relationship between muscle loading and personality factors in a different fashion. The participants in this study were undergraduate and graduate students in the college of engineering. The memory tasks used were specific to healthcare occupation and required dealing with medical terms. It is likely that because of their unfamiliarity with the vocabulary used in the memory tasks, participants may have felt increased stress levels. Furthermore, only short-term exposure to workplace stressors utilizing isometric exertions was evaluated in this study. A long term exposure to workplace stressors characterized by different types of physical exertions (dynamic, intermittent) may be more harmful because of muscle fatigue issues, further changing interpersonal response to workplace stressors. Additionally, in this study muscle activation only during physical exertions were studied. It is possible that a combination of physical and mental exertions may affect the muscle activation during mental tasks. Future study should investigate the effect of physical demand on muscle loading during mental tasks. Finally, only two personality types, based on the information processing preference, were evaluated. The MBTI questionnaire provides 16 personality classifications. Future research should investigate additional personality types to more precisely understand the impact of personality factors in the development of work-related neck and shoulder MSD.

5. Conclusion

The modifying effect of mental stress on biomechanical loading of upper extremities during low levels of force exertion has been stated in numerous studies; however, only a few studies evaluate such relationships during heavy physical exertions. The current study demonstrates that mental stress also plays a significant role during heavy physical exertions. The activation of the shoulder as well as the neck muscles increased significantly with the addition of mental demand. The interacting effect of mental and physical demand on biomechanical loading found to be influenced by individual personally trait. Participants with feeling personally showed a higher increase in the muscle activation corresponding to similar exposure of mental and physical demands than thinking personally. This indicates that response to mental stress during physically demanding tasks seems to be mediated by individual personality, further implying that personality type may play an important role in the MSD development pathway.

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