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# Empirical evaluation of neck muscle fatigue generated by healthcare related exertions

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ABSTRACT

In this study, the effect of healthcare related physical and psychosocially stressful exertions on neuromuscular fatigue of the neck muscles was investigated. Eighteen healthy individuals (16 male, 2 female) performed force exertions commonly used during bed-to-stretcher patient transfer tasks under both the presence and absence of psychosocially stressful conditions. Surface electromyography (SEMG) data from two neck muscles and subjective workload ratings using the NASA Task Load Index (TLX) were collected. The SEMG data was processed and analyzed using discrete wavelet transform (DWT) to quantify development of neuromuscular fatigue. The power of the lower fatigue frequency band (12–23 Hz) was found to be significantly higher during physical exertions performed under psychosocially stressful conditions than physical exertion alone, indicating a faster fatigue development. Significantly higher NASA TLX workload scores for mental demand, temporal demand, and frustration were observed during combined physical and psychosocial exertions. The results of this study suggest that, in addition to the actual physical work, overall psychosocial stress in the work environment should be considered when designing work-rest schedules during long work shifts to reduce incidences of highly prevalent work-related neck musculoskeletal disorders among healthcare workers.



## 1. Introduction

Work-related musculoskeletal disorders (MSDs) are the most common cause of morbidity and disability among healthcare workers. Recent Bureau of Labor Statistics (BLS) data indicates that in the United States, occupational injuries and illnesses in the healthcare and social assistance industries occurred at a higher incidence rate than all private industries (BLS, 2011). In 2010, the MSD incidence rate for nursing aides, orderlies, and attendants increased by 10% to 249 cases per 10,000 full-time workers (BLS, 2011). This population also had an overall 7% increase in the total number of MSD cases. Although most MSDs among healthcare workers occur in the lower back, in recent years, prevalence and incidence rates of neck MSDs have shown an increasing trend. Based on a survey of 1163 randomly-selected nurses employed in Illinois and New York, Trinkoff et al. (2002) reported a prevalence rate of 47%, 46%, and 35% for MSDs of the lower back, neck, and shoulder, respectively. In a similar type of study conducted in the states of Ohio and Kentucky, annual prevalence rates of severe musculoskeletal symptoms in the lower back, neck, and shoulder were found to be 49%, 33%, and 33%, respectively (Daraiseh et al., 2010). Harcombe et al. (2009) reported a 12-month prevalence rate of 57%, 52%, and 39% for MSDs of the lower back, neck and shoulder, respectively, among the registered nurses in New Zealand ($n = 181$). In another survey study, Smith et al. (2006) reported that MSDs of the shoulder (71.9%) were the most common among Japanese nurses ($n = 1162$) followed by the lower back (71.3%) and neck (54.7%). Among Iranian registered nurses ($n = 375$), the frequencies of musculoskeletal symptoms of the back, neck, and shoulder were reported to be 52%, 60%, and 52%, respectively (Choobineh et al., 2010). In a recent study by Andersen et al. (2012), chronic pain prevalence of 23% and 28% were reported for the lower back and neck/shoulder, respectively, among the Danish healthcare workers ($n = 8952$).

Work-related neck pain is believed to have multidimensional etiologies. Among healthcare workers, the risk factors that are frequently associated with neck MSD consist of physical and psychosocial demands. With the advent of patient handling devices, physical demands associated with the manual handling of patients, especially lifting, at healthcare workplaces has been reduced greatly. However, pushing and pulling exertions during tasks such as repositioning/turning patients and transferring patients in and out of bed are still manually performed by healthcare workers (Choobineh et al., 2010; Kim et al., 2011; Pompeii et al., 2009). In addition to physically demanding exertions, healthcare workplaces are characterized by high levels of psychosocial stress due to the

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presence of factors such as cognitive overload, working under time pressure, conflicts with patients and relatives of patients, disagreements with management, differences of opinion with physicians, and dealings with patients suffering and deaths (Camerino et al., 2001; Gunnarsdottir et al., 2003; Herin et al., 2011; Jaworek et al., 2010; Salminen et al., 2003). A significant interactive relationship between the work-related psychosocial stress, physically demanding exertions, and symptoms of neck pain is reported in a number of investigations (Aasa et al., 2005; Johansson, 2008; Long et al., 2011; Simon et al., 2008; Van Yperen and Hagedoorn, 2003; Warming et al., 2009).

Overexertion is the common denominator for most work-related MSDs among healthcare workers. In 2010, nearly 49% of the MSD cases among healthcare workers were attributed to overexertion (BLS, 2011). A combined exposure to the physical and psychosocially stressful exertions present in the healthcare setting is likely to trigger early muscle fatigue, which can lead to overexertion and an increased risk of musculoskeletal disorders (Janet Torma-Krajewski et al., 2008). Currently, the effect of physical exertions performed under psychosocially stressful conditions on the development of neuromuscular fatigue of neck muscles is not well understood. Therefore, the purpose of this study was to evaluate the impact of healthcare related physical and psychosocially stressful activities on the development of neuromuscular fatigue of the neck muscles. Surface electromyography (SEMG) was used for the objective assessment of neuromuscular fatigue and the NASA Task Load Index (TLX) was used to measure subjective workload. It was hypothesized that fatigue generated by a combined exposure to physical and psychosocial exertions will be higher than exposure to physical exertions alone.

## 2. Materials and methods

### 2.1. Protocol overview

In this study, two experimental sessions were used to simulate physical and psychosocially stressful exertions that are common in the healthcare setting. In session 1, an isometric pulling task that simulates force exertion during bed-to-stretcher patient transfer was used to evaluate fatigue generated by physical demands alone. A similar type of physical exertion was used in a number of previous studies to evaluate the effect of healthcare related physical demand on the musculoskeletal loading of the upper extremities and low back (Table 1). During session 2, in addition to the physical exertions (same as session 1), cognitively demanding exertions were used to evaluate fatigue generated by a mix of physical and psychosocially stressful exertions. SEMG data from the sternocleidomastoid (major anterior neck muscle) and cervical trapezius (major posterior neck muscle) muscles were recorded for the objective assessment of fatigue. NASA Task Load Index (TLX) scores were obtained using six subscales (menal demand, physical demand, temporal demand, performance, effort, frustrations) for the subjective work-load assessment.

### 2.2. Participants

Eighteen university engineering student (16 males and 2 females) were recruited for this study. The average (*SD*) age, weight, and height of the participants were 25 (2.5) years, 162.4 (22.7) lbs, and 173 (9.7) cm, respectively. All participants were free of acute and chronic upper extremity injuries and had no known neurological disorders or heart conditions. 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 then asked to read and sign a consent form approved by the local Institutional Review Board.

### 2.3. Equipment

#### 2.3.1. Surface electromyography system

A 16-channel telemetry EMG system (Noraxon Inc., AZ, USA) was used for data collection. This system consists of bipolar Ag/AgCl pre-gelled surface electrodes (1 cm diameter, inter-electrode distance is 2 cm), pre-amplified lead wires, and a Telemyo 2400T transmitter. The pre-amplifiers on the lead wires have a band-pass of 10–500 Hz (gain 500), CMRR > 100 dB, and Input Impedance > 100 MΩ. The frequency of EMG data acquisition was set at 1500 Hz.

#### 2.3.2. Pulling exertion device

A custom-made isometric force exertion device was used to simulate a bed-to-stretcher patient transfer task (Fig. 1). This device consists of a 6-in. wide slotted steel plate (Fig. 1a) and a series 5 advanced digital force gauge (Mark-10 Corporation, NY, USA) with a double handle attachment (Fig. 1b). The force gauge and double handle attachment connect with the steel plate using a slide and lock mechanism (Fig. 1c). This mechanism allows vertical adjustability of the force gauge and double-handle attachment along the plate and can be locked at any position. Cloth sheets were wrapped around the double handle attachment during the force exertion to make the simulated patient transfer task more realistic.

### 2.4. Experimental protocol

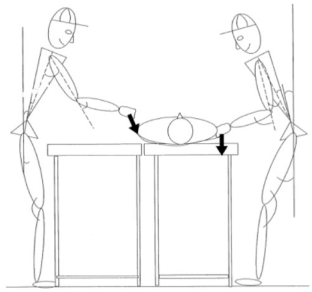
Upon arriving at the laboratory, participants were provided with a tour of the experimental set-up. Participants received an explanation of the equipment, data collection procedures, and specifics of the experimental tasks and were subsequently asked to consent to being study participants. Demographics and anthropometric measures were then recorded for each participant.

Participants were subsequently instrumented with the surface electrodes for SEMG data collection. 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 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., 2010). SEMG from the cervical trapezius muscle was measured by placing an electrode between the occipital and C7, at the level of C4 (approximately 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., 2010).

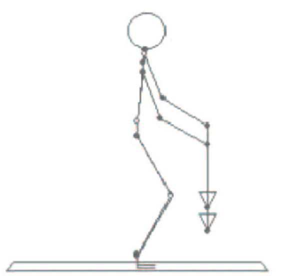
#### 2.3.3. Experimental session 1

The participant performed 10 maximal isometric pulling tasks simulating the force exertion during bed-to-stretcher patient transfer tasks at a frequency of 1/min. 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 away from the column of the pulling exertion device with the right foot placed in front of the left foot (approximate anterior–posterior distance of 30–35 cm between the feet). The trunk and knee joints were flexed 10–20 degrees and 5–10 degrees, respectively. The shoulder joint was flexed 50–55 degrees with no abduction/adduction. The elbow joint was flexed 5–10 degrees with 50–55 degrees of supination and the wrist was in a neutral posture. A picture of a participant performing the pulling task is shown in Fig. 1. During the pulling exertion,

**Table 1**
Patient handling tasks evaluated in the previous studies.


(a)


(b)


(c)


(d)


(e)


(f)


(g)


(h)

(a) A stretcher to gurney patient transfer task studied by Lavender et al.,(2000)

(b) Lab-based simulation used by McGill and Kavcic, (2005) to study bed to stretcher patient transfer.

(c) Patient handling posture studied by Jang et al., (2007) to evaluate the risk of low back injury.

(d) Posture used by healthcare workers during a patient transfer task (Pullen Jr, 2008).

(e) One of the most commonly used patient handling postures – discussed by Schibye et al., (2003)

(f) Posture used to move a patient in a bed before transferring to a stretcher (Skotte et al., 2002)

(g)(h) Lateral patient transfer tasks discussed by Nelson et al., (2003)

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 5 s. During the 10 s following each exertion, the 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 (Fig. 2).

*2.3.4. Experimental session 2*

The participant performed a mix of physical and psychosocially stressful exertions during this session. The physical tasks were the same as session 1 and the total duration of session 2 was also 10 min. Psychosocial stress was generated using mentally demanding tasks. Previously, mentally demanding tasks were used by Allread and Marras (2006) and Marras et al. (2000) to experimentally generate psychosocial stress in the lab setting. 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 and performing arithmetic calculations. Healthcare workers perform various skill-based tasks in daily work activities, such as remembering patients' medications, recalling physical therapy schedules, and checking vital signs.

Before each isometric pulling task, participants were presented with new information consisting of lists of symptoms, diseases,


**Fig. 1.** (a) Picture of the pulling exertion device and (b) a participant performing isometric pulling task simulating force exertion during bed-to-stretcher patient transfer task.

and recommended prescription drugs to remember for 30 s. While reading the new information, participants also performed 3 arithmetic calculations. Immediately following the pulling exertion (5 s), participants were questioned based on the information presented for the next 10 s. Participants then rated the perceived workload using the NASA TLX (10 s). A rest period of up to 10–15 s was provided before the beginning of the next mental task. Task division and the corresponding time allotment during sessions 1 and 2 are shown in Fig. 2. The order of session 1 and 2 were randomized between the participants.

### 2.5. Data processing and analysis

The SEMG data from the sternocleidomastoid and cervical trapezius muscles during the first 3 ($T_0$) and last 3 ($T_{10}$) physical tasks (isometric pulling task) were used for the analysis. Spectral analysis of SEMG signals using Fast Fourier transform (FFT) has been widely used in the past for the objective assessment of fatigue. A shift in the mean and median frequencies of the power spectrum to the lower end with the development of fatigue is observed in a number of studies (Dolan et al., 1995; Hostens and Ramon, 2005; Potvin, 1997; Roy et al., 1998; von Tscharner et al., 2003). The SEMG signal is assumed to be stationary in the spectral analysis based on the FFT (Reaz et al., 2006). Under non-stationary or pseudo-stationary conditions, which is likely to be the state of SEMG signals recorded during a mix of activities, discrete wavelet transform (DWT) of SEMG signals has been recommended as a more appropriate method for fatigue assessment (Gonzalez-Izal et al., 2010; Hostens et al., 2004; Sparto et al., 2000). Unlike FFT, where timing information is completely lost, DWT simultaneously elucidates local spectral and temporal information from a signal in a more flexible way by employing a window of variable width

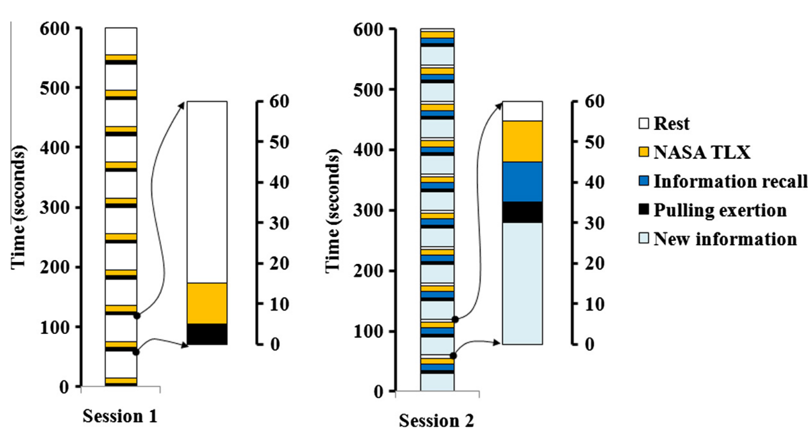



**Fig. 2.** Task and time distribution during sessions 1 and 2.

(Kumar et al., 2003; Sparto et al., 2000). Therefore, in this study, fatigue generated by a mix of physical and psychosocially stressful exertions was studied using DWT of the SEMG signal.

DWT was computed by passing the signal $X[n]$ through a series of high pass $H[n]$ and low pass $L[n]$ filters to analyze the high and low frequencies, respectively. The output of the high-pass and low-pass filters are the details coefficients ($y_{high}[m]$) and approximate coefficients ($y_{low}[m]$), respectively (Hussain et al., 2009). The filter outputs were then downsampled as expressed in the following equations:

$$Y_{low}[m] = \sum_n X[n] * l[2m - n] \quad (1)$$

$$Y_{high}[m] = \sum_n X[n] * H[2m - n] \quad (2)$$

The above procedure was repeated for subsequent decomposition of the signal. Previous studies have identified an increase in the power of the lower frequency band of 5–30 Hz , also known as the fatigue frequency band, as a reliable index of fatigue (Dolan et al., 1995; Kumar et al., 2003). A possible biomechanical basis for the increase in power with development of fatigue begins with the fact that a SEMG signal is a spatio-temporal summation of motor unit's action potential trains (Vukova et al., 2008). The changes in the power spectrum of the SEMG signal is mainly attributed to the deviations in the shape of the motor unit action potential, firing rate, and muscle fiber conduction velocity (Broman et al., 1985; Moritani et al., 1982; Potvin, 1997; Vukova et al., 2005). Under fatigued conditions, a decline in the conduction velocity reduces excitation–contraction coupling, further affecting the force generation ability of a muscle (Allen, 2004; Bigland-Ritchie et al., 1978; Brody et al., 1991; Colliander et al., 1988; Dolan et al., 1995). Enhanced recruitment of motor units, i.e., an increase in the firing rate of motor units (Cairns et al., 1998; von Tscharner et al., 2003; Vukova et al., 2008) is needed in order to maintain similar force levels. This increase in the firing rate of the motor unit increases the power of the fatigue frequency band (Sparto et al., 2000).

In this study, the SEMG signal was decomposed at 7 levels and the power of the lower frequency band of 12–23 Hz was used for the evaluation of neck muscle fatigue. The decomposition process is shown in Fig. 3. The raw SEMG signal was decomposed to get the detailed coefficients (CD1) and approximation coefficients (CA1) during the first level of decomposition. The approximation coefficients CA1 were further decomposed into the second-level of detail and approximation coefficients. The process was continued further to get detail coefficient CD7 and approximate coefficient CA7 at the seventh level of decomposition.

The ability of DWT to estimate features from the signal is dependent on the impulse response of the high pass and low pass filters which is a function of the mother wavelet used for signal decomposition. Different types of wavelets such as Symlet, Discrete Meyer, BiorSplines and Daubechies, were used in the previous studies for the assessment of neuromuscular fatigue. In our recent study, we evaluated the 10 most commonly used wavelet functions and found that Reverse Biorthogonal with 3.1 scale (Rbio3.1) was the most appropriate wavelet function to study fatigue induced spectral changes of SEMG signals (Chowdhury et al., 2012). In this study, the Rbio3.1 wavelet function was used to compute DWT. The wavelet toolbox of MatLab (The MathWorks, Inc., MA, USA) was used for the analysis. Data from each physical exertion was decomposed separately and the power of the 12–23 Hz frequency band was estimated using the following equation:

$$Power = \sum_{i=1}^{n} (a_1 + a_2 + \cdots + a_{n-1} + a_n)^2 \quad (3)$$

where $a_1$ to $a_n$ are the detailed coefficients at the 6th level of decomposition.

Power of the 12–23 Hz frequency band was treated as the dependent variable in the statistical analysis.

NASA TLX data was processed to calculate adjusted ratings for each subscale. To obtain adjusted ratings, the raw rating for each subscale in the NASA TLX was multiplied by its weight, i.e., perceived contribution of that subscale to the workload. Previous studies have indicated that obtaining weights at the end of each subtask can increase sensitivity of the derived workload scores only slightly and did not warrant the additional time required to gather them (Hendy et al., 1993). Therefore, weights were obtained at the end of each session. The averages of the raw ratings provided by the participants during a session were multiplied by their weights to calculate weighted ratings for the different subscales. These adjusted ratings of different subscales were treated as dependent variables in the statistical analysis.

### 2.6. Statistical analysis

A two-way general linear ANOVA (analysis of variance) was performed to test the effect of type of exertion and duration of exertion on the fatigue of the sternocleidomastoid and cervical trapezius muscles. A one-way general linear ANOVA was performed to test the effect of type of exertion on workload assessed using NASA TLX. Type of exertion was treated as a fixed effect with two levels: (1) physical exertion (session 1); (2) physical and psychosocially stressful exertion (session 2). Duration was also treated as a fixed factor with two levels: (1) start of the session ($T_0$); (2) end of session ($T_{10}$). Participants were treated as a random factor. The adequacy of the linear model was confirmed by using normal probability plots of residuals between the actual and fitted values. Significant main and/or interaction effects were further evaluated by conducting comparison between means using Tukey's Honestly Significant Difference (HSD) all-pairwise comparison test.

## 3. Results

The mean of forces exerted during the isometric pulling tasks performed during sessions 1 and 2 were 301.5 (96.3) N and 328.0

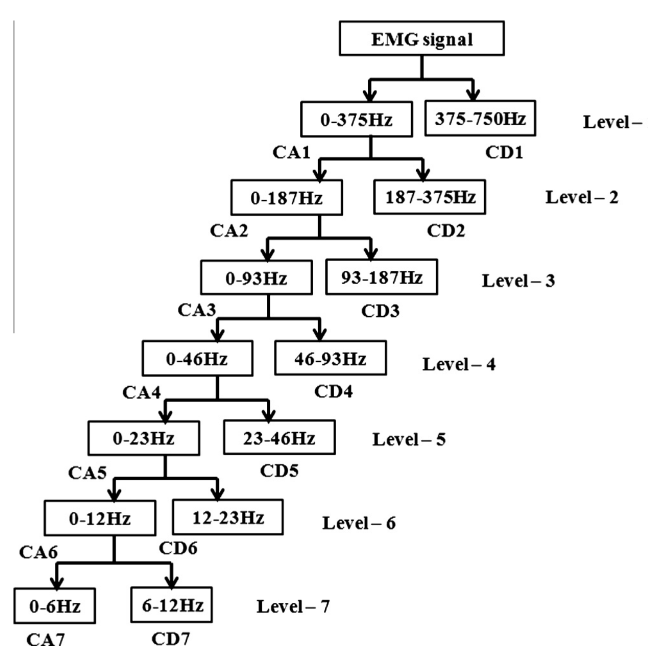



**Fig. 3.** Discrete Wavelet Transform (DWT) based decomposition of the SEMG signal and the corresponding frequency bands.

**Table 2**
Main effect of type of exertion and duration of exertion on the power of 12–23 Hz frequency band. Numbers in the parenthesis represent one standard deviation.

| | Type of exertion (*a*) | | | Duration of exertion (*b*) | | | $a \times b$ |
|---|---|---|---|---|---|---|---|
| | Session 1 | Session 2 | *P*-value | $T_0$ | $T_{10}$ | *P*-value | *P*-value |
| Sternocleidomastoid | 202.0(251.5) | 530.3(1003.2) | 0.000 | 277.4(339.5) | 452.6(992.4) | 0.052 | 0.048 |
| Cervical trapezius | 1359.5(2411.4) | 2699.8(3804.5) | 0.000 | 1713.7(2581.0) | 2345.6(3785.9) | 0.054 | 0.000 |

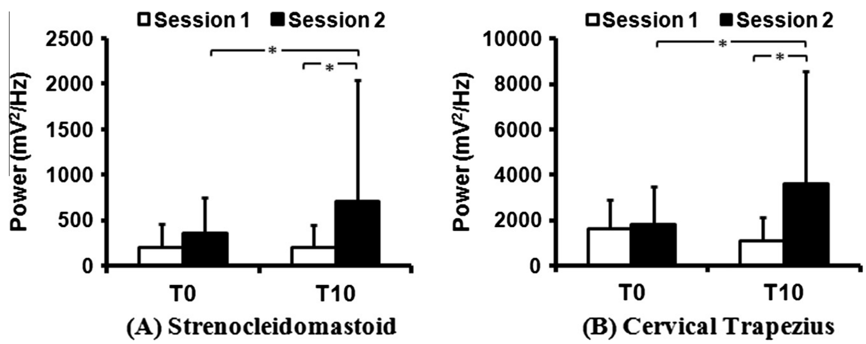



**Fig. 4.** Mean power of 12 Hz to 23 Hz frequency band at the start ($T_0$) and the end ($T_{10}$) of the sessions 1 and 2. Error bars represent one standard deviation.

(96.0) N, respectively. Statistically, no difference was found in the magnitudes of forces exerted during the two sessions ($P = 0.415$).

### 3.1. Muscle fatigue

Type of exertion significantly affected power of the 12–23 Hz frequency band. For both neck muscles, a significantly higher power was observed during session 2 compared to session 1 (Table 2). The effect of time on the power of the 12–23 Hz frequency band was also statistically significant. Both neck muscles showed higher power towards the end of the session ($T_{10}$) than at the beginning of the session ($T_0$) (Table 2). A significant interaction between type of exertion and duration of exertion was observed for the sternocleidomastoid ($P = 0.048$) and cervical trapezius ($P < 0.001$) muscles. Results of the Tukey HSD all-pairwise comparison test showed that the mean power during session 2 was significantly higher at $T_{10}$ than at $T_0$ (Fig. 4). No difference in the mean power at $T_0$ and $T_{10}$ was observed during session 1. Mean power at $T_{10}$ during session 2 was significantly higher than the corresponding mean power at $T_{10}$ during session 1 (Fig. 4).

### 3.2. NASA TLX

The means of weighted ratings for all categories of the NASA TLX are shown in Fig. 5. The mean of weighted ratings for mental demand ($P < 0.001$), temporal demand ($P < 0.001$), and frustration ($P = 0.004$) were significantly higher during session 2 than session 1. The mean of weighted ratings for physical demand ($P < 0.001$) was significantly higher during session 1 than 2. No difference in the means of weighted ratings for performance ($P = 0.062$) and effort ($P = 0.895$) were observed between the two sessions.

## 4. Discussion

This study investigated the effect of healthcare related physical and psychosocial stressful exertions on neuromuscular fatigue of the neck muscles. SEMG data recorded from the anterior (sternocleidomastoid) and posterior (cervical trapezius) neck muscles were analyzed using DWT to compute the power of the 12–23 Hz frequency band. Results of the study showed that the power of the 12–23 Hz frequency band, also known as the fatigue

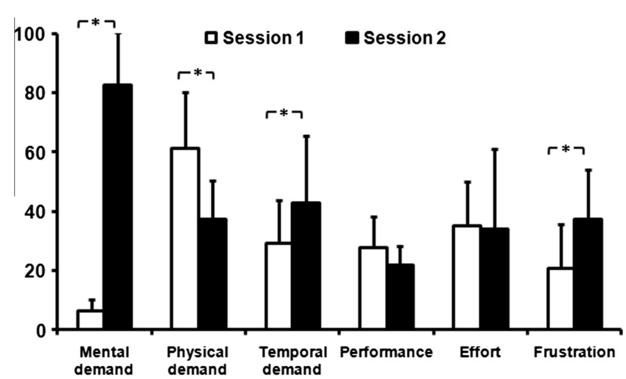



**Fig. 5.** Mean of weighted ratings for different NASA TLX subscales during the sessions 1 and 2. Error bars represent one standard deviation.

frequency band (Kumar et al., 2003), was significantly higher when physical exertions were performed under psychosocially stressful conditions, indicating higher muscle fatigue development compared to when physical exertions were performed normally.

A significant interaction between type of exertion and duration of exertion on the power of the fatigue frequency band was also observed for both neck muscles investigated in this study. Physically demanding tasks performed under psychosocially stressful condition resulted in faster fatigue development. Psychosocially stressful conditions are known to draw on the mental reserve of the workers and can cause cognitive dissonance due to increased neuromotor noise (Bloemsaat et al., 2005; Davis et al., 2002). A few studies have postulated that an increase in the muscle tension or stiffness is one of the filtering strategies used by the muscles to attenuate this enhanced noise (Bloemsaat et al., 2005). It is likely that psychosocially stressful exertions performed during session 2 of this study developed sustained muscle tension triggering faster fatigue development.

Significantly higher NASA TLX workload scores for mental demand, temporal demand, and frustration were observed during session 2, clearly indicating that the protocol used in this study successfully generated psychosocial stress. Despite identical force exertion levels and longer rest periods during physical tasks, significantly higher workload scores for physical demand during session

1 compared to session 2 were observed. The scale used to estimate adjusted workload ratings for individual subscales (e.g. physical demand, mental demand, etc.) combines the subscale ratings (reported after each exertion) that are weighted based on the contribution of each subscale to the perceived workload. For example, physical demand may be the primary source of the workload for a physically demanding task performed under normal conditions and therefore may receive the highest weight and the overall adjusted rating. When a similar task is performed under extreme time pressure, temporal demands may become the primary source of workload (may receive higher weight than physical demand) and can reduce the adjusted rating for physical demand, even though a similar physical task is being performed. During session 1 of this study, only the physical exertions were performed and therefore physical demand was perceived as the only/primary source of the workload and received the highest weights and overall adjusted ratings. During session 2, with the addition of mental tasks, which were challenging to most of the participants because of their unfamiliarity with the medical terms, mental demand was perceived as the primary source of workload and received the highest weight among all the subscales. The physical demands were rated to a similar level, but the perceived weights were lower in session 2 than in session 1, causing the observed decrease in the adjusted rating of physical demands in session 2. In this study, relatively short durations of experimental sessions (10 min) were used; yet, significant increases in the power toward the end of the experimental session were observed. In the real world setting, healthcare workers work long shifts (8–12 h). These workers are mostly engaged in various psychosocially stressful activities, prior or subsequent to physically demanding patient handling tasks. Even though forces are not exerted by the muscles during psychosocially stressful activities, results of this study seem to indicate that increased muscle tension during such exertions performed prior or subsequent to the forceful exertions significantly affect the muscle fatigue development process. Therefore, it is essential that overall psychosocial stress in the work environment is considered in addition to the actual physical work when designing work-rest schedules during long work shifts. Appropriate administration of rest periods may avoid early development of neuromuscular fatigue and subsequently reduce incidences of highly prevalent work-related neck MSDs among healthcare workers.

There are a few limitations of this study that need to be acknowledged. Memory tasks were used in this study to experimentally simulate psychosocial stress. Although this is one way of manipulating stress, other methods such as uncooperative behavior and time pressure, could also be used. It is likely that these factors may collectively or independently affect the fatigue development process. Future studies should investigate the interactive relationship between various other psychosocial stress related variables and concurrent physical demand on the fatigue development process. The study participants were undergraduate and graduate students in the college of engineering. The memory tasks used were specific to healthcare occupations and required knowledge of 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. Future studies using professional healthcare workers will further enhance our understanding of the fatigue development process in psychosocially stressful healthcare environments. Furthermore, standardized isometric exertions were used in this study to simulate physical demands. This might be different from the real world situation, where workers perform different types of physical exertions (dynamic, intermittent). Future studies should examine the effect of a mix of exertions on the fatigue development process.

## 5. Conclusion

Healthcare workers perform physically demanding patient handling tasks while dealing with a wide range of psychological stressors on a daily basis. The combined effect of such exertions on the development of neuromuscular fatigue of the neck muscles has not been previously investigated. The results of the present study have shown that neuromuscular fatigue for the investigated neck muscles developed at a faster pace when physically demanding exertions were performed under psychosocially stressful conditions. Overall perception of workload in terms of mental demand, temporal demand, and frustration were also higher during combined physical and psychosocial exertions. Faster development of fatigue and higher perception of workload during physical exertion performed under psychosocially stressful settings seems to suggest an increased risk of neck musculoskeletal disorders in such work settings.

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