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Impact of shoulder position and fatigue on the flexion–relaxation response in cervical spine

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ABSTRACT

Background: Neck pain is common among general population with a high prevalence among the people who are routinely exposed to prolonged use of static head–neck postures. Prolonged static loading can cause localized muscle fatigue which may impact the stability of the cervical spine. In this study, flexion–relaxation phenomenon was used to study the post fatigue changes in the stability of cervical spine by evaluating the synergistic load sharing between muscles and viscoelastic elements.

Methods: Thirteen male participants were recruited for data collection. The variables that influence cervical flexion–relaxation were studied pre- and post-fatigue using neutral and shrugged shoulder postures. The Sorensen protocol was used to induce neck extensor fatigue. Surface electromyography and optical motion capture systems were used to record neck muscle activation and head posture, respectively.

Findings: The flexion–relaxation phenomenon was observed only in the neutral shoulder position pre- and post-fatigue. The flexion relaxation ratio decreased significantly post-fatigue in neutral shoulder position but remained unchanged in shrugged shoulder position. The onset and offset angles and the corresponding durations of the silence period were significantly affected by the fatigue causing a post-fatigue expansion of silence period.

Interpretation: The muscular fatigue of neck extensors and shoulder position was found to modulate the cervical flexion–relaxation phenomenon. Early shifting of load sharing under fatigued condition indicates increased demands on the passive tissues to stabilize the cervical spine. Shrugging of shoulder seems to alter muscular demands of neck extensors and make cervical flexion–relaxation phenomenon disappear due to continuous activation of the neck extensors.

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1. Introduction

Musculoskeletal disorders (MSD) of the neck are common. Among the general population, an annual prevalence of neck pain was reported to be between 30 and 50% (Hogg-Johnson et al., 2008a). It is also estimated that about 67% of the people suffer neck pain at some point in their life (Côté et al., 2004). Recent Unites States Bureau of Labor Statistics (US BLS) data indicated that work-related neck pain requires a median of 11 days away from work to recuperate compared to 5 days for all other body parts combined. The economic impact of work related neck pain may vary considerably between the working populations; the social impact is enormous in terms of human suffering and morbidity.

The occupations that see relatively high prevalence of neck pain includes video display terminal (VDT) user, surgeons, sewing machine operator, and dentist (Côté et al., 2009; Hagberg and Wegman, 1987). The work activities by these occupations demand use of static and/or awkward head–neck postures for sustained durations which can cause static loading of the musculoskeletal structures. Prolonged static loading leads to localized muscle fatigue which may impact the stability of the cervical spine. A less stable spine can be both a cause and consequence of spinal pain (Ariens et al., 2000; Ariëns et al., 2001; Palmer et al., 2001).

Spinal stability is achieved by the highly coordinated interaction of active and passive components of the neuromuscular systems. Viscoelastic behavior of the neck system, baseline muscle activation and reflexive activation of muscles stabilize the cervical spine (Simoneau et al., 2008). The viscoelastic behavior contributes to the passive stiffness, whereas active stiffness is provided by both baseline muscle activation and reflexive activation of muscles (Hendershot et al., 2011). A few studies on the lumbar spine have reported a reduction in passive support of the spine following a prolonged trunk flexion (Sánchez-Zuriaga et al., 2010; Shin and Mirka, 2007) and proposed that the active stiffness plays an important role to maintain spinal stability (Hendershot et al., 2011). Baseline activation is typically measured using the flexion–relaxation phenomenon (FRP) and sudden perturbation protocols are used to quantify the muscle reflex responses (Olson et al., 2004; Solomonow et al., 2003). Prior cervical spine studies based on the sudden perturbation protocol primarily looked at the effect of load, torque and torso acceleration to better understand the mechanism of whiplash injuries (Forbes et al., 2012; Simoneau et al., 2008; Tangorra et al., 2003).

The FRP explains the synergistic load sharing between the muscles and viscoelastic elements (ligaments, disks, capsules, and fascia). For the cervical spine, during head flexion, cervical extensors gradually increase

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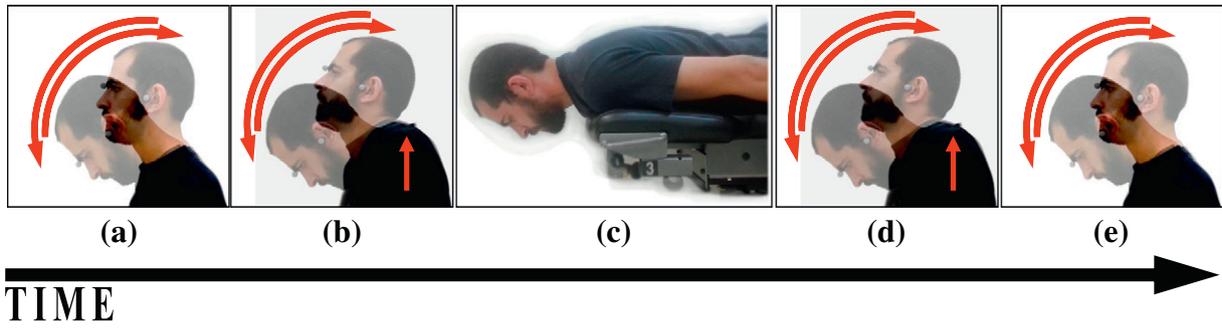*E-mail address:* nimbarte.ashish@gmail.com (A.D. Nimbarte).

Fig. 1. Sequence of activities performed during the data collection. Three head flexion extension trials were recorded in neutral (a) and shrugged (b) shoulder postures each, followed by the fatigue inducing Sorensen protocol (c). Head flexion extension trials were repeated in neutral (e) and shrugged (f) shoulder postures immediately after the Sorensen protocol. The order in which shoulder postures were tested pre- and post-fatigue was randomized between the participants.

extension trials in neutral and shrugged shoulder postures each, followed by the fatigue inducing Sorensen protocol. Immediately after the Sorensen protocol, the participants again repeated head flexion extension trials in neutral and shrugged shoulder postures (Fig. 1). The order in which shoulder postures were tested under normal and fatigued conditions was randomized between the participants.

2.5. Data analysis

2.5.1. Data processing

The raw marker data was reconstructed, labeled, gap filled and exported as XYZ coordinates. A vector from the midpoint of two TMJ markers to the glabellar bone marker was defined. The orientation of this vector with the horizontal axis of the lab-coordinate system was identified as the flexion–extension angle. Standard neutral head position was used to define zero flexion–extension angle. The raw EMG data was demeaned, full-wave rectified, and low-pass filtered at 4 Hz using a fourth-order Butterworth filter to form linear envelops.

The baseline flexion relaxation response of the cervical extensors was estimated using the Flexion–Relaxation Ratio (FRR), onset and offset angles of silent period, and silence period expansion. The FRR was calculated by using Eq. (1) and is defined as the ratio of the maximum EMG activation in phase 4 to the average EMG activation in phase 3 (Alschuler et al., 2009; Lehman, 2012; Murphy et al., 2010). The inverse of FRR < 40% was used to judge the presence of FRP (Pialasse et al., 2009).

$$FRR = \frac{\text{Maximum EMG in phase 4}}{\text{Average EMG in phase 3}} \tag{1}$$

Onset and offset angles were identified using the Instantaneous Flexion Relaxation Ratio (IR_i) (Eq. (2)). The flexion angle corresponding to $IR_i < 40\%$ was defined as the onset angle. The extension angle corresponding to $IR_i > 40\%$ was defined as the offset angle (Pialasse et al., 2009). Onset and offset angles were expressed as the percentage of maximum flexion to standardize across subjects.

$$IR_i = \frac{EMG_i}{\text{Peak EMG in phase 4}} \tag{2}$$

where, EMG_i is the instantaneous muscle activity at any time i.

The time differences between the onset angle and start of phase 2 (T1), and the offset angle and end of phase 2 (T2) were calculated to estimate the silent period expansion using the following equations:

$$\text{Silent period expansion} = Onset\ Shift + Offset\ Shift \tag{3}$$

where,

$$Onset\ Shift\ (T1) = T1_{Post\_Fatigue} - T1_{Pre\_Fatigue} \tag{4}$$

$$Offset\ Shift\ (T2) = T2_{Post\_Fatigue} - T2_{Pre\_Fatigue}. \tag{5}$$

The start and end of phase 2 were defined using a criterion of two standard deviations below the mean of full flexion angle using a moving window of 100 data points.

2.5.2. Statistical analysis

The equality of variance and normality test demonstrated that the assumption of the homoscedasticity and normal distribution was true. Therefore, a two-factor general linear analysis of variance (ANOVA) was performed to evaluate the effect of fatigue and shoulder posture on the baseline flexion relaxation parameters. The fatigue and shoulder posture were treated as fixed effects and participants as random factor. FRR, onset angle, offset angle and silent period expansion were the dependent variables. Minitab 16 statistical analysis software (Minitab Inc., PA, USA) was used to perform the analysis.

3. Results

The average time until muscle fatigue was 678 (180) s. Statistically, no differences were found in FRR, onset angle, offset angle, T1 and T2 (P-values were 0.91, 0.92, 0.91, 0.91, and 0.99, respectively) between right and left neck extensors. Therefore, the data was pooled from both sides for further statistical analysis.

The FRP was observed in 100% of the subjects in the neutral shoulder position pre- and post-fatigue (Fig. 2). In shrugged shoulder position, the FRP was only observed visually in 2 of the participants pre-fatigue, but did not follow the $IR_i < 40\%$ criteria. FRP was absent in all the participants in the shrugged shoulder position post-fatigue. Consequently, T1 and T2 values were only estimated for neutral shoulder position.

The FRR was significantly affected by the fatigue status ($P < 0.001$) and shoulder posture ($P < 0.001$) (Fig. 3). The interaction effect of fatigue and shoulder posture on the FRR was also statistically significant ($P < 0.001$). The average FRR in neutral shoulder position was significantly higher than in shrugged shoulder position. Pre-fatigue FRR in neutral shoulder position was significantly higher than post-fatigue FRR. However, in shrugged position, no differences were found in the pre- and post-fatigue FRR.

The onset and offset angles, and T1 and T2 values were significantly affected by the fatigue in neutral position (Fig. 4). The average onset angle decreased significantly by 13% of full flexion post-fatigue ($P < 0.001$). A rather small but significant decrease (2.8% of full flexion) in the offset angle was observed post-fatigue ($P < 0.001$). Post-fatigue T1 was significantly higher than pre-fatigue T1 ($P < 0.001$), resulting in an onset shift of 0.55 (0.28) seconds (Fig. 5). The corresponding T2 values also increased significantly ($P < 0.001$), resulting in an offset shift of 0.21 (0.09) seconds. The post-fatigue expansion of silence period was 0.76 (0.37) seconds.
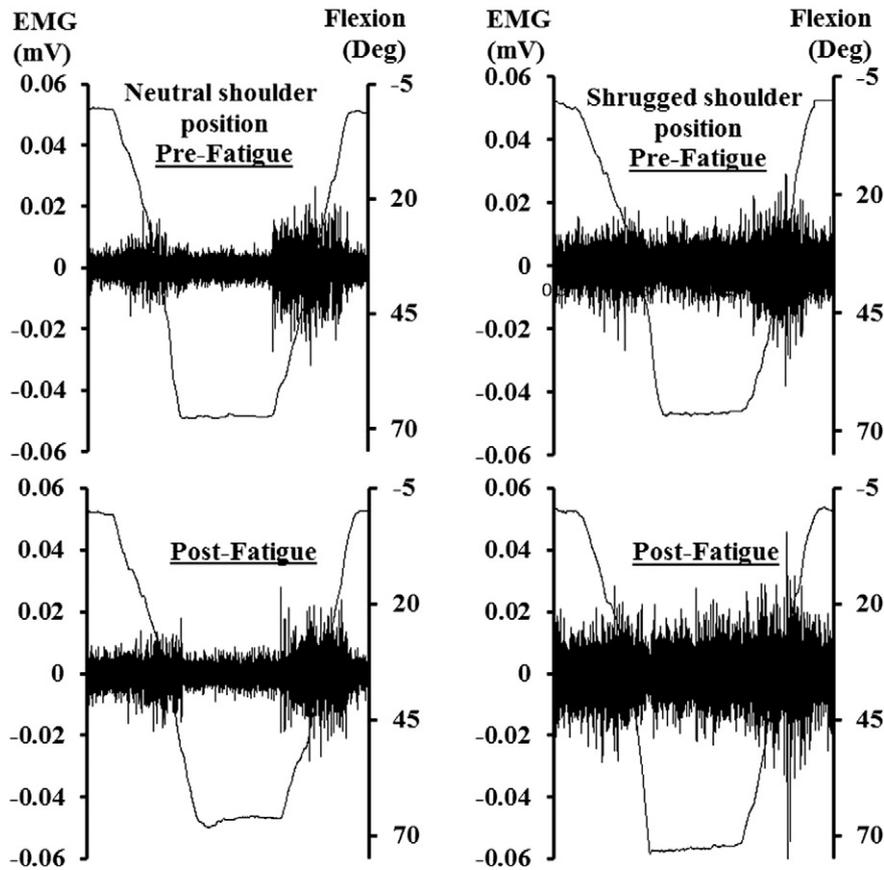
Fig. 2. Raw EMG and head flexion extension data for one of the subjects during four experimental conditions.

4. Discussion

In this study, the effect of muscular fatigue of neck extensors and shoulder posture on the cervical FRP was evaluated. The muscular fatigue of neck extensors was found to modulate the FRP by decreasing the FRR and expanding the silent period. Similar findings were previously reported for the effect of fatigue on the FRP in the lumbar spine (Descarreaux et al., 2008; Olson et al., 2004; Pialasse et al., 2010; Shin and D'Souza, 2010). The post-fatigue decrease in the FRR was mainly due to the increased activation of neck extensors during the relaxation phase. An average activation during phase 3 increased by 20% post-fatigue. Under fatigued condition, changes in the concentrations of calcium ions

(Ca^{2+}) and lactic acid negatively impact muscle fiber excitation–contraction coupling (Allen, 2004; Kurebayashi and Ogawa, 2001). As a consequence, increased motor unit firing rate is required to maintain similar force exertion levels especially during isometric exertions (Vukova et al., 2008). The increased muscular activation during the relaxation phase could be due to the augmented firing rate of the motor units that isometrically counteract the effect of gravity on the head.

Post-fatigue expansion of silence period was produced by both increased onset and offset shifts. The fatigued extensor muscles due to their inability to stabilize the cervical spine possibly shifted the load sharing to the passive tissues much before the deep flexion resulting in an early onset of silence period. During the extension, due to the same reason, it is possible that the deep neck muscles have generated
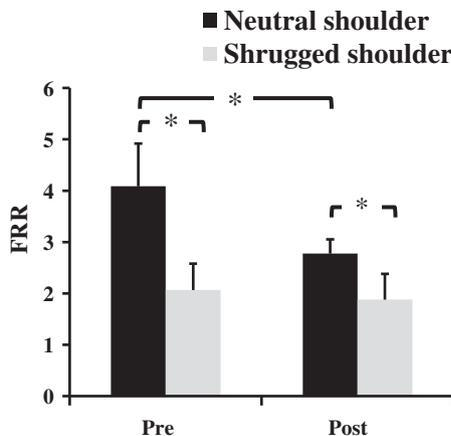
Fig. 3. Average pre- and post-FRR in neutral and shrugged shoulder positions. Error bars represent one standard deviation. Bars at the end of the brackets are statistically significant.
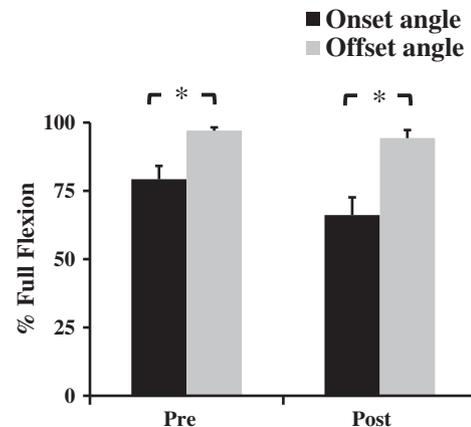
Fig. 4. Average onset and offset angles pre- and post-fatigue in neutral shoulder position. Error bars represent one standard deviation.
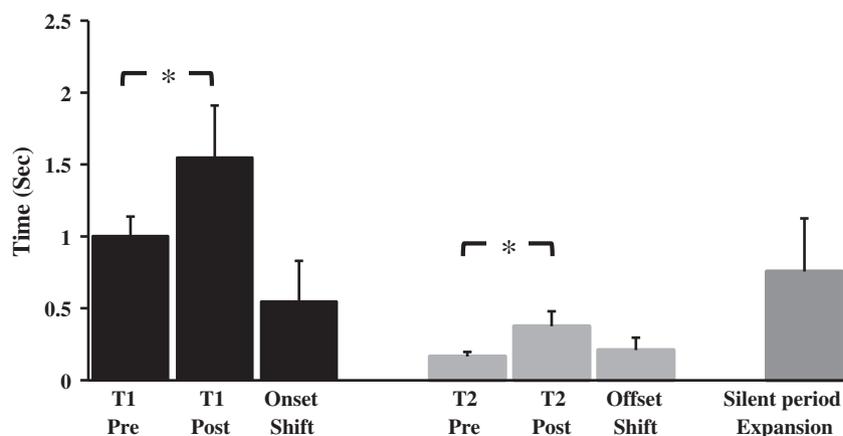
Fig. 5. Onset and offset shifts and silent period expansion pre- and post-fatigue. Error bars represent one standard deviation.

the extension moment decreasing the offset angle and delaying the cessation of silence period. The onset shift was almost 4 fold the offset shift indicating a more pronounced contribution by the passive viscoelastic tissues than deep muscles in stabilizing the cervical spine under fatigued condition. For the lumbar spine it has been proposed that deep back muscles initiate trunk extension in the fatigued condition whereas the superficial muscles initiate trunk extension in the non-fatigued condition (Descarreaux et al., 2008). A very small offset shift observed in this study does not seem to fully support this notion for the cervical spine. On the other hand, it is also likely that the Sorenson protocol used in this study may have fatigued the deep muscles to some extent (perhaps lesser than superficial muscles) affecting their ability to generate the extension moment producing a narrow offset shift. Intramuscular recording would be required to further confirm deep and superficial muscle synergies pre- and post-fatigue.

The FRP was not observed when shrugged shoulder position was used. This is partly because neck extensors work continuously to elevate the scapula in the shrugged shoulder position. Previous studies have reported that the neck muscles stabilize the shoulder joints during physical exertions. Neck flexors stabilize the sternoclavicular joint, whereas the neck extensors stabilize the acromioclavicular joint (Nimbarte, in press). Andersen et al. (2008) have reported that shrugging the shoulder can induce an activation of up to 70% maximum voluntary contraction (MVC) for the neck extensors. This reorganization in muscular demand for shrugged shoulder condition may require continuous firing of neck extensors to make the silence period disappear. For a very few participants, a brief silence period was observed pre-fatigue, but disappeared completely post-fatigue. This can be due to the increased firing rate of motor units post-fatigue as explained earlier. Furthermore, it is also likely that the laxity of the viscoelastic tissues is affected by the shrugged shoulder position, requiring compensatory contribution by the neck extensors.

The results of this study demonstrate that shoulder orientation had an effect on the variables that influence the FRP. The shrugged shoulder posture tested in this study is different from the typical post-fatigue shoulder postures commonly adopted by the workers in the occupational settings (rounded and/or forward tilted shoulder). Most of these postures are as a result of passive stretching of viscoelastic structures unlike the shrugged shoulder position tested in this study, which is mostly produced by the contraction of active tissues. The shoulder postures induced by passive stretching are likely to affect the FRP behavior in a different manner. Previous studies on passive stretching of viscoelastic structures (creep) and the FRP of the lumbar spine reported a contraction of silence period due to delayed cessation and early activation of the active tissues (Dickey et al., 2003; Solomonow et al., 2003). Future studies should look at the effect of different passive shoulder postures on the cervical FRP. Furthermore, in this study post-fatigue changes in the stability of the cervical spine were studied by examining

the behavior of only one group of (extensor) muscles. As noted previously, highly coordinated interaction of many different muscles around the neck is required to achieve the stability of the cervical spine. Future studies should examine various other neck muscles.

For normal symptom free individuals, results of this study indicate an early shift in the load sharing to the passive tissues and an increased activation by the active tissues during the silence period, post-fatigue. For the individuals suffering from either traumatic neck pain or idiopathic chronic neck pain an early onset of fatigue is expected. The mechanism of the fatigue and the resulting changes in the FRP may vary based on the actual diagnosis. Active tissue weakness may trigger early fatigue onset due to reduced tolerance and/or endurance of the neck muscles. This may result in an early shift in the load sharing to the passive tissues, reduced muscle activation during the silence period, and increased FRR. On the other hand, damaged passive structure may increase the contribution required by the neck muscles to maintain stability resulting in an early onset of fatigue. This may result in delayed shift in the load sharing to the passive tissues, increased muscle activation during the silence period, and decreased FRR. Lower FRR among the participants with the symptoms of low back pain due to passive tissue damage was previously reported compared to symptom free individuals by some researchers (Gupta, 2001; Watson et al., 1997). Altogether, a distorted load sharing between active and passive tissues may put the symptomatic individuals at an increased risk of injury with sustained or repetitive exposure to fatiguing exertions.

Our results for the onset and offset angles, especially for the pre-fatigue condition, were slightly higher than the results reported in earlier FRP studies (Maroufi et al., 2012; Pialasse et al., 2009, 2010). We reported 79.2% and 97.1% for pre-fatigue onset and offset angles respectively, compared to 73–76% and 91–92% reported in earlier FRP studies. The difference could be due to the variability in the criteria used to identify these angles. Most of the previous studies used visual inspection, while a quantitative method ($IR_i < 40\%$, Mean ($2 \times SD$)) was used in this study to define these angles. Another possible explanation is that the motion of the lumbar and thoracic spines was not controlled or recorded during the neutral standing posture. Consequently, some participants might have inadvertently flexed their back leading to higher onset and offset angle values (Burnett et al., 2009; Meyer et al., 1993).

There are a few limitations of this study that need to be acknowledged. First, only male participants were tested in this study. Gender is one of the non-modifiable risk factors of work related neck pain (Hogg-Johnson et al., 2008b), with significantly higher prevalence being reported among females than males (Côté et al., 2008; Fejer et al., 2006; Widanarko et al., 2011). Different physical features such as anthropometry, strength, flexibility, pain tolerance, endurance, etc. are proposed to affect the work methods used by females in order to balance work demands with work ability. Future studies should test

participants of different gender. Second, lack of data on scapular kinematics during shrugged shoulder trials. To adopt the shrugged shoulder the participants were instructed to move their scapula upward toward the head to their maximum ability. Although, all the participants were closely watched during the data collection to assure consistent postures across the participants, the actual kinematic data would have provided a better estimate of the changes in the shoulder posture and the resulting changes in the laxity of neck extensors. Third, neck muscle fatigue was not assessed using objective EMG data. An indirect subjective method (CR-10 Borg discomfort scale) was used to measure muscle fatigue. Previous studies have reported high correlation between the CR-10 Borg discomfort ratings and the fatigue measured using objective EMG data (Chowdhury et al., 2013; Dedering et al., 2002).

5. Conclusions

The results of this study indicated that fatigue and shoulder position modulate cervical FRP. Fatigue may temporarily influence the stability of the cervical spine, resulting in an early engagement of the passive tissues, yet requiring substantial muscular activation to maintain functional stability. Shoulder position (shrugging) produced by contraction of active tissues was also found to influence the cervical FRP. Interaction of passive shoulder positions and fatigue, among the symptomatic individuals may provide further insights into the stability and fatigue induced ailment of the cervical spine.

Conflict of interest

None of the authors has any conflict of interest.

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