



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 United 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 include 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; Ariens 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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their activation to compensate for the increasing effect of gravity on the mass of the head. In the fully flexed posture, the strained viscoelastic elements generate force sufficient to offset the effect of gravity, resulting in a reduced activation of the extensors (Meyer et al., 1993). The FRP for the cervical spine was first reported by Meyer et al. (Meyer et al., 1993). Subsequently a number of studies compared population with symptoms of neck pain with healthy controls using FRP parameters (Maroufi et al., 2012; Murphy et al., 2010). A diminished FRP was reported in the symptomatic population. Various task related factors such as load, computer use, sitting posture, and backpack carrying also reported to affect the cervical FRP parameters indicating increased load sharing by the passive cervical tissues (Lee et al., 2011; Pialasse et al., 2009, 2010; Yoo et al., 2011).

Despite the ability of FRP to reflect the load-sharing interaction of the active and passive components of the cervical spine, the effect of muscular fatigue on the FRP parameters of the cervical spine is currently unknown. A few previous studies have documented that fatigue alters the head–neck and shoulder postures during task completion. For example, forward head and rounded shoulder postures (Szeto et al., 2002) are observed among the users following sustained use of computer. Such postures may influence the muscular efforts of the cervical extensor affecting their compensatory role in stabilizing the cervical spine. The inter-association between such shoulder posture and the baseline behavior of cervical extensor during FRP pre- and post-fatigue have also not been well understood. Therefore, the purpose of this study was twofold. First, the effect of fatigue on the baseline flexion relaxation response of the cervical extensors was studied. It was hypothesized that the muscular fatigue would affect the period of diminished muscular activity in a full flexion posture. Second, the effect of shoulder posture on the baseline flexion-relaxation response of the cervical extensors was studied. It was hypothesized that the shoulder posture would alter muscular efforts of the cervical extensor further affecting their baseline flexion-relaxation response.

2. Methods

2.1. Participants

Thirteen healthy male participants were recruited for data collection. All the participants were engineering graduate students and their age, weight, and height were 29.8 (7.3) yrs, 72.8 (12.2) kg, and 172.8 (5.4) cm, respectively. The primary inclusion criteria used in this study required that the participants were free from any type of musculoskeletal disorders and had no history of neck and/or shoulder injury or notable neck pain that required medical care over the last twelve months. The participants were screened for cardiac and other health issues (e.g., chest pain, dizziness, and heart problems) using the Physical Activity Readiness Questionnaire (PAR-Q, British Columbia Ministry of Health). Written informed consent was obtained from all participants. The consent form was approved by the local institutional review board.

2.2. Instrumentation

2.2.1. Electromyography (EMG) system

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

2.2.2. Optical motion analysis system

Kinematic data was recorded using an eight-camera optical motion-capture system (Vicon Motion Systems, LA, USA). A set of retro-reflective markers was used to collect the kinematic data at a rate of

100 Hz. Vicon Nexus 1.7.1 software was used to record motion as well as the EMG data. EMG data streams were synchronized with motion capture data by acquiring the analog EMG data using a Vicon ADC (analog-to-digital converter) screw terminal box.

2.3. Experimental design

A two-factor factorial design was used. Factor 1, fatigue was treated at two levels (with and without). The Sorensen protocol was used to induce neck muscle fatigue (Lee et al., 2004, 2005). Factor 2, shoulder posture, was treated at two levels (neutral and shrugged). Neutral shoulder posture was a normal standing posture with leveled and relaxed shoulders (Fig. 1 (a) (e)). The participants were instructed to move their scapula upward toward the head as much as they can (Fig. 1 (b) (d)).

2.4. Data collection

First, the experimental set-up, equipment, and data collection procedures were explained to the participants. Subsequently, the following stepwise procedure was used to collect the experimental data.

2.4.1. EMG data collection preparation

The EMG activity of neck extensors was measured by placing surface electrodes bilaterally at the C4 level (approximately the mid-cervical region). To determine the C4 level a horizontal line was drawn above the C7 level at 2.5 times the distance between the C6–C7 vertebrae. The electrodes were placed parallel to the muscle fiber (approximately 35° to the vertical line between the C7 and C4) (Nimbarte et al., 2010). Prior to the electrode placement, the skin underneath the anatomical landmarks was shaved (if needed) and cleaned with 70% alcohol pads.

2.4.2. Kinematic data collection preparation

Three 14 mm retro-reflective markers were attached to the head; one on the glabellar bone in the forehead area and the other two on each side of the head at the proximal aspect of the temporomandibular joint (TMJ).

2.4.3. Experimental procedure

The participants performed head flexion extension trials using neutral and shrugged shoulder postures pre- and post-fatigue. Three trials of head flexion extension were collected for each shoulder posture. The Sorensen protocol was used to induce neck muscle fatigue (Lee et al., 2004, 2005). The participants lay prone on a table with arms on the sides and shoulders (acromion) level with the edge of the table (Fig. 1 (c)). Neck muscle fatigue was induced by exposing the head and neck to gravitational forces. The level of neck discomfort was observed continuously every minute during the Sorensen protocol using a CR-10 Borg discomfort scale. Subjects were encouraged to maintain this position as long as possible. The Sorensen protocol was discontinued when a score of 8 on the Borg scale was reached. A level of 8 was used to stop the Sorensen procedure to prevent the risk of excessive fatigue or possible injury.

During each head flexion extension trial, the participants were instructed to stand in a neutral stance with arms maintained on the sides. To control the starting head position, subjects were asked to look at a fixed point adjusted to their standing eye height. Subjects maintained the neutral position (phase 1) for approximately 2 s, fully flexed the neck with the goal of approximating their chin to their upper chest (manubrium) within 5 s (phase 2), maintained full flexion for 5 s (phase 3), and extended their neck to the neutral position within 5 s (phase 4). Participants' movement was controlled using a metronome with audible sound. The tempo of the metronome was set at 1 beat/s. The participants were instructed to maintain a fixed trunk and shoulder posture throughout the head flexion extension trial to prevent bending of the trunk and/or forward movement of the head. No rest pauses were given during the data collection procedures. Thus, the complete data collection procedure consisted of three head flexion

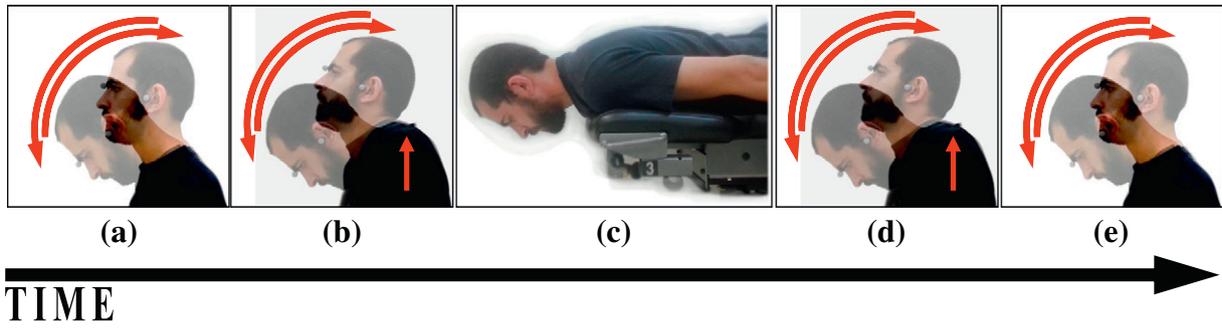


Fig. 1. Sequence of activities performed during the data collection. Three head flexion extension trials were recorded in neutral (a) and shrugged (b) shoulder postures each, followed by the fatigue inducing Sorensen protocol (c). Head flexion extension trials were repeated in neutral (d) and shrugged (e) 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 envelopes.

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).

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

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.

$$IR_i = \frac{EMG_i}{\text{Peak EMG in phase 4}} \quad (2)$$

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:

$$\text{Silent period expansion} = \text{Onset Shift} + \text{Offset Shift} \quad (3)$$

where,

$$\text{Onset Shift } (T1) = T1_{\text{Post_Fatigue}} - T1_{\text{Pre_Fatigue}} \quad (4)$$

$$\text{Offset Shift } (T2) = T2_{\text{Post_Fatigue}} - T2_{\text{Pre_Fatigue}} \quad (5)$$

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.

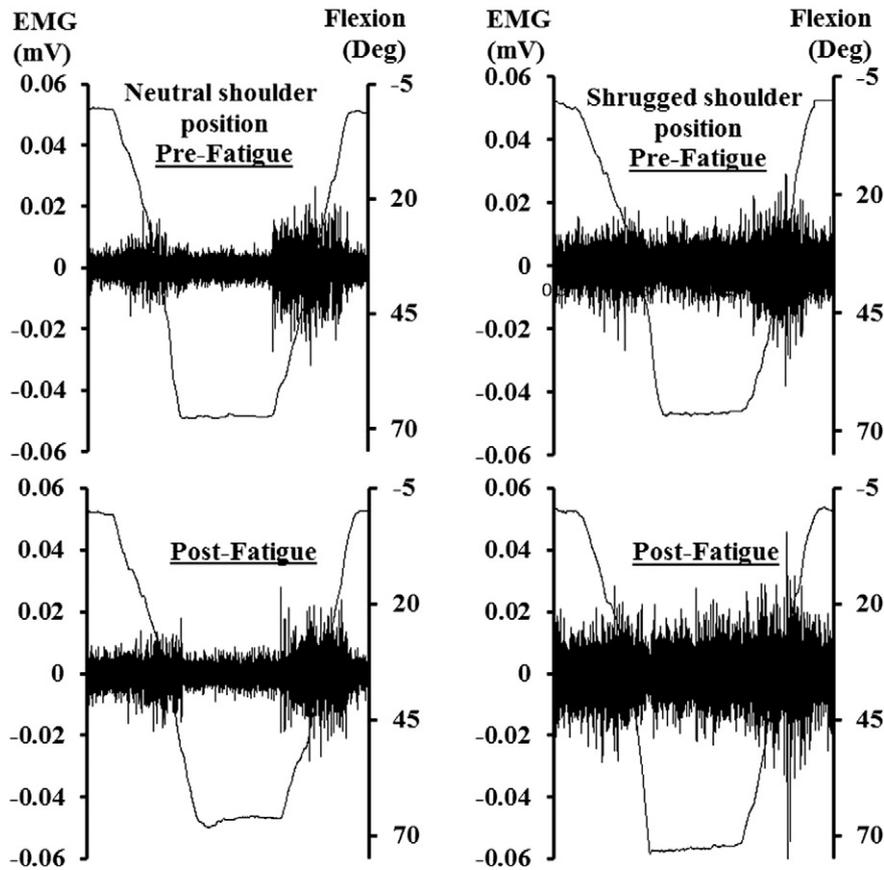


Fig. 2. Raw EMG and head flexion extension data for one of the subjects during four experimental conditions.

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

(Ca²⁺) 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

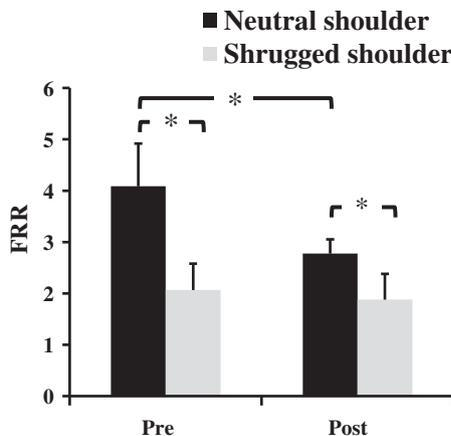


Fig. 3. Average pre- and post-FRR in neutral and shrugged shoulder positions. Error bars represent one standard deviation. Bars at the end of the brackets are statistically significant.

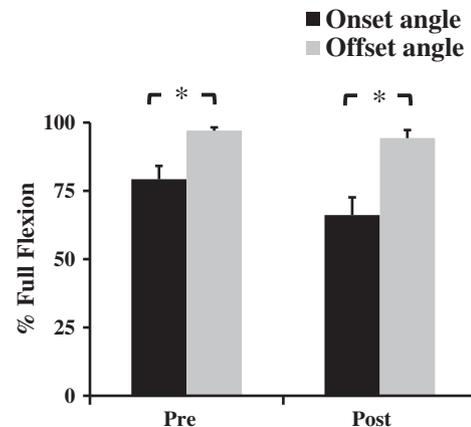


Fig. 4. Average onset and offset angles pre- and post-fatigue in neutral shoulder position. Error bars represent one standard deviation.

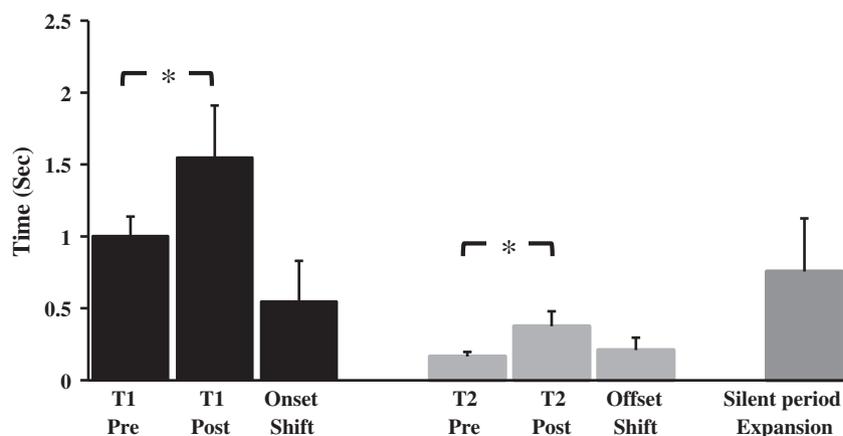


Fig. 5. Onset and offset shifts and silent period expansion pre- and post-fatigue. Error bars represent one standard deviation.

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 (Nimbarde, *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; Dederling 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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