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Flexion-relaxation response induced by neck extensor muscle fatigue

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Abstract

Fatigue induced neck or cervical spine pain is a common problem among various occupational groups. Flexion-relaxation (FR) behavior of the extensor muscles provides an effective method for the assessment of neuromuscular impairment. Although a few studies have shown a significant impact of muscle fatigue on the FR parameters for lumbar spine, currently, the effect of fatigue on the FR parameters for cervical spine is not well studied. Therefore, the objective of this study was to evaluate the effect of fatigue on the neck extensor muscles' FR parameters. Muscle activity and kinematic data from 10 healthy male subjects were recorded using surface electromyography and optical motion capture systems, respectively. The Sorensen protocol was used to induce neck extensor muscle fatigue. Results suggest that fatigue significantly altered the FR ratio by reducing it from 4.09 before fatigue to 2.78 after fatigue. Also, fatigue significantly decreased the onset and offset angles resulting in a larger myoelectric silence period. These changes in the FR parameters suggest a post fatigue shift in the load-sharing towards passive stabilizing structures due to the degraded force generating capacity of the fatigued muscles, which can be a risk factor for neck pain.

Keywords
Flexion-Relaxation, cervical spine, muscle Fatigue

1. Introduction

Neck musculoskeletal disorders (MSD) are common among working as well as general population. About 67% of people suffer neck pain at some time during their lives [1]. For the general population, an incidence rate of 15.5–213 per 1000 person-years was reported for neck pain by Hogg-Johnson et al [2]. Among the working populations, the highest incidence rate of neck pain of 36 to 57.5 per 100 worker-year was reported for office workers and computer users [3]. The cost estimates for work-related MSD range from €2.1 billion for neck and upper limb symptoms in Netherlands to $45 to $54 billion for all musculoskeletal disorders in the USA [4] .

The alteration in the neuromuscular activation patterns of the cervical spine muscles is one of the causes of neck pain [5]. Of several methods used to investigate abnormal spinal muscle activation and pain development, Flexion-Relaxation (FR) behavior of the paraspinal extensor muscles [5-7] is a commonly used approach. Flexion-Relaxation Phenomenon (FRP) is defined as the myoelectric silence of the paraspinal extensor muscles during full flexion [8-9], and represent a load sharing mechanism between active (muscles) and passive (such as ligaments, fascia and bones) tissues [10-13]. The parameters that are typically used to characterize FRP include the Flexion Relaxation Ratio (FRR), the onset and offset angles and the duration of myoelectric silence period. The FRR is generally estimated by dividing the maximal muscle activity during extension phase by the average muscle activity during full flexion phase [14-15] . The onset and the offset angles correspond to the beginning and the end of the myoelectric silence during full flexion [16-19]. A reduction in FRR and an early onset and delayed offset of the silence period indicate a reduced force generation ability of the paraspinal extensor muscles, causing increased load sharing by the passive stabilization structures.

For normal healthy people with no symptoms of neck or back pain, FRR of around 4 was observed for cervical and lumbar spine. In people with pain symptoms, a reduced FRR of 2 was reported [12, 14, 20-21]. Onset and offset angles of around 76% and 93% of the maximum flexion, respectively, were reported for normal people [12, 18, 20, 22-23]. A number of factors such as musculoskeletal loading, sustained flexion, fatigue, task repetition and velocity were found to modulate these angles and the corresponding onset and cessation of the flexion-relaxation response for lumbar spine [16-19, 22, 24-27].

Understanding the factors that modify FR parameters is important to identify the risk factors for work-related MSDs. As noted, several studies have investigated the FRP in the lumbar spine region. Consequently, several factors, such as static posture, repetitive exertions, speed, musculoskeletal loading were identified as the risk factors for the work-related low back MSD. The purpose of this study was to quantify the effect of fatigue on the FR parameters for cervical spine. For lumbar spine, a post fatigue reduction in the onset and offset angles from 80% to 74% and from 93% to 85%, respectively, was reported in a previous study [16]. In this study, it was hypothesized that neck extensor muscle fatigue will reduce the cervical spine FRR and increase the duration of the myoelectric silence period.

2. Methodology

2.1 Approach:

Human participants performed a simple cervical flexion-extension task under normal and fatigued conditions. Submaximal isometric exertion-based Sorensen protocol was used to induce neck extensor muscles fatigue. Myoelectrical activity of extensor muscles was used to assess the changes in the FRR, and head kinematics were studied to quantify changes in the timing and magnitude of onset and offset angles.

2.2 Participants

Ten healthy male participants were recruited for data collection. The participants were graduate students at West Virginia University. Age, weight, and height of the subjects were 26.4 ± 2.7 yr, 70.7 ± 8.2 kg, and 170.1 ± 5.1 cm, respectively. All participants were free of acute and chronic neck, shoulder, or other upper extremity MSDs and had no known neurological disorders. The Physical Activity Readiness Questionnaire (PAR-Q, British Columbia Ministry of Health) was used to screen participants for cardiac and other health problems (e.g., dizziness, chest pain, and heart trouble).

2.3 Apparatus/tools

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

2.3.2 Optical motion analysis system: Cervical spine kinematic data was recorded using an eight-camera optical motion-capture system (Vicon Motion Systems, LA, USA). Marker data was sampled at a rate of 100 Hz using 14mm retro-reflective markers.

2.4 Data collection

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

2.4.1 EMG data collection preparation

EMG activity of the cervical extensor muscles was measured by placing surface electrodes at the C4 level (approximately the mid-cervical region). The C4 level 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 35º) to the vertical line between the C7 and C4 [28]. The skin underneath the anatomical landmarks was shaved (if needed), abraded, and cleaned with 70% alcohol, prior to the placement of the SEMG electrodes. SEMG data were collected bilaterally.

2.4.2 Kinematic data collection preparation: Three makers were placed on the head; one on the glabellas bone in the forehead area and the other two on each side of the head at the proximal aspect of temporomandibular joint (TMJ).

2.4.3 Experimental procedure

During testing, subjects stood in a neutral stance with arms on the sides and eyes positioned at a fixed point directly in front of the head to maintain the same starting head position. Subjects maintained the neutral position (Phase 1) for 2 seconds, flexed their neck with the goal of approximating their chin to their upper chest (manubrium) within 5 seconds (Phase 2), maintain full flexion for 5 second (Phase 3), and then extend the neck back to neutral/starting position within 5 seconds (Phase 4) (Figure 1). A metronome was used to control subjects' movement. This procedure was repeated 3 times under non-fatigued and fatigued conditions. The Sorensen protocol was used to induce neck muscle fatigue [29-30]. The participant lay prone on a table with shoulders (acromion) level with the edge of the table and arms maintained on the sides (Figure 2). Neck and head were not supported and exposed to gravitational forces to induce neck muscle fatigue. Participants were encouraged to maintain this position as long as possible. To ensure subjects safety, neck pain and level of discomfort was monitored during the Sorensen protocol every minute using a 10 point Borg discomfort scale (1 = Nothing at all and 10 = Very severe pain or discomfort). The Sorensen protocol was completed when subjects could not maintain the unsupported neck and head posture or they reached a score of 8 on the Borg scale, whichever occurred first.

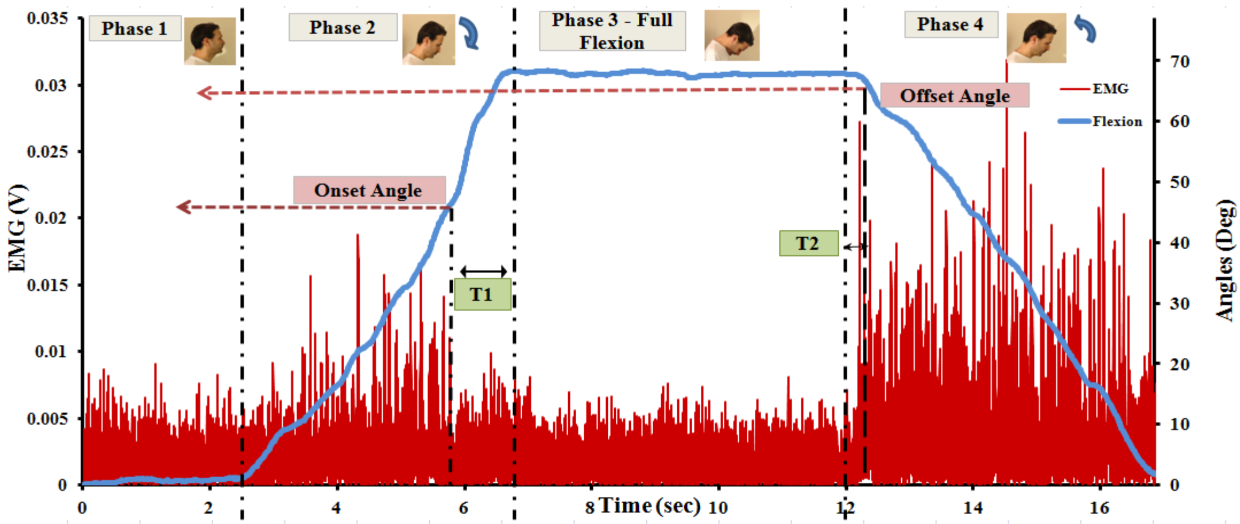

Figure 1: EMG and kinematic data during cervical a flexion-extension trial and the corresponding FR phases and parameters.

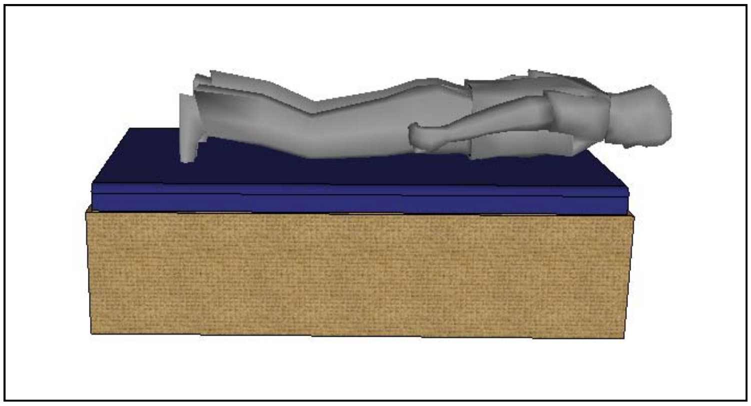

Figure 2: Subject performing Sorensen Protocol

2.5 Data Analysis

2.5.1 Data Processing:

The raw EMG signals were demeaned, full-wave rectified and low pass filtered at 4Hz using a fourth-order Butterworth filter. The raw marker data was reconstructed, labeled, gap filled and exported as XYZ coordinates. These coordinates were used to establish a local coordinate frame at the head segment such that the origin is at the midpoint of the two TMJ markers. X-axis pointed forward from the origin to the glabellas bone marker. Y-axis pointed to the left from the origin to the left TMJ marker and Z-axis was a cross product of X and Y axis, pointed upward following a right-hand rule. The orientation of the X-axis with the horizontal was estimated as the flexion-extension angle. Head position in the standard neutral standing position was treated as the 0 flexion-extension angle.

The FRR was determined using equation (1) [18]. A ratio lower than 40% was used to determine presence and absence of FRP.

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

Instantaneous Flexion Relaxation Ratio (IR_i) (equation 2) was used to estimate onset and offset angles. The onset angle was identified when IR_i decreased to 40%, and the offset was identified when IR_i increased back to 40% (Figure 1). Onset and offset angles were calculated as a percentage of maximum flexion to standardize across the participants.

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

Where, EMG_i is the EMG value at any time i

Furthermore the time differences between the onset angle and full flexion (T1), and the offset angle and full flexion (T2) (Figure 1) were estimated to calculate the silent period expansion using the following equations:

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

Where,

$$Onset\ Shift\ (T1) = T1_{POST} - T1_{PRE} \quad \text{.................. (4)}$$

$$Offset\ Shift\ (T2) = T2_{POST} - T2_{PRE} \quad \text{.................. (5)}$$

2.5.2 Statistical analysis:
One way ANOVA was used to study the effect of fatigue on the FR parameters. The independent factor fatigue was treated at two levels, pre-fatigue and post-fatigue. The dependent factors were the FRR, onset and offset angles, and the silent period expansion. Statistical analysis was performed using SPSS statistical software version 20.0 (SPSS, Chicago, IL, USA).

3. Results
The FRP was observed in all the participants. No significant differences were found in the FRR, onset angles, offset angles, T1 and T2 data collected from the right and left side (*p*-values were 0.999, 0.984, 0.864, 0.837, and 0.963, respectively) and therefore data was pooled from both sides for further statistical analysis. The average endurance time until muscle fatigue (Sorensen protocol) was 673 (190) sec with a scored rating of 8 on the Borg discomfort scale.

The FRR was significantly affected by muscular fatigue ($p < 0.001$). A pre-fatigue FRR of 4.09 (0.83) reduced to a post-fatigue FRR of 2.78 (0.28) (Figure 3). The onset and offset angles of the silence period were also significantly affected by the fatigue ($p < 0.001$ and $p < 0.05$, respectively). Onset angle decreased from 78.9% (4.4%) to 66.9% (5.9%) (Figure 4). The offset angle decreased from 97.1 % (0.8%) to 94.1 % (2.7%) (Figure 4).

The onset shift and offset shift and the resulting silent period expansion were significantly affected by the muscle fatigue ($p < 0.001$ for all). The onset shift increased from 1.04 (0.15) to 1.52 (0.31) sec (Figure 5), and the offset shift was increased from 0.16 (0.04) to 0.41 (0.16) sec (Figure 5). The silent period expansion increased by 0.73 (0.42) sec (Figure 5).

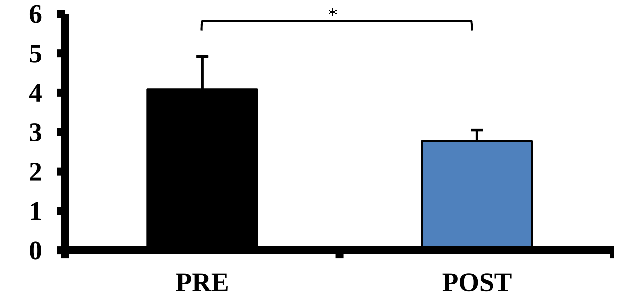

Figure 3: FRR – Pre and Post Fatigue showing. Error bars are with 1 SD.
* Bars at the end of the brackets are significantly different at α = 0.05

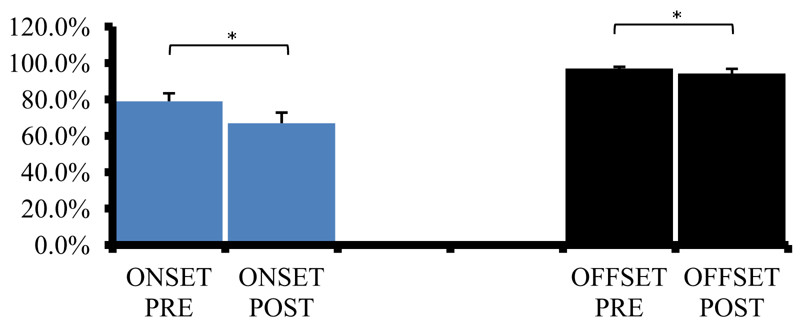

Figure 4: Onset and Offset Angles (% of Maximum Flexion) – Pre and Post Fatigue.
Error bars are with 1 SD. * Bars at the end of the brackets are significantly different at α = 0.05

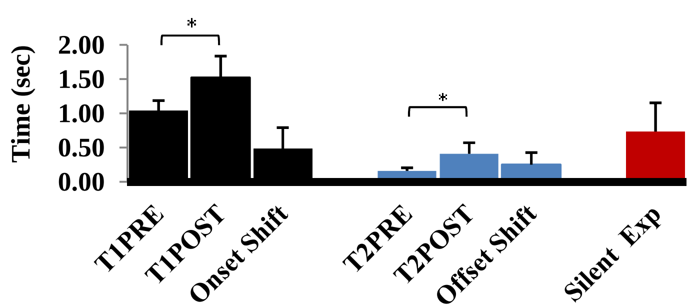

Figure 5: Onset and Offset shifts and Silent Period Expansion. Error bars are with 1 SD.
* Bars marked with the brackets are significantly different.

4. Discussion

This study was conducted to investigate the effect of neck extensor muscle fatigue on the cervical spine FR parameters. Results of this study indicated that muscular fatigue of the neck extensor muscles alters the cervical spine FR by reducing the FRR and increasing the duration of silence period. These results support our hypothesis and are congruent with a number of existing lumbar spine studies [16, 24-26]. The observed reduction in FRR from 4.09 to 2.78 was due to the increased activation of neck extensor muscles during 3rd phase. This higher muscle activation is attributed to the increased laxity of spine stabilizing structures caused by fatigue [27] .

Both onset and offset angles were significantly decreased due to muscle fatigue from 78.9% to 66.8% and from 97.1% to 94.1%, respectively. The pre-fatigue onset and offset angle reported in this study are slightly different (higher) than the previous FR studies [18, 20, 22]. The possible reasons for this difference could be the method used to report the onset and offset angles. In most of these previous studies onset and offset angles of around 75% and

92% reported using visual inspection, while a quantitative criteria (FRR<40%) was used in this study. Secondly, in this study, standing posture was used and thoracic and lumbar spine motion was not controlled. As a result, some subjects might have unintentionally flexed their back causing higher onset or offset angles [9, 31] .

The decreased onset and offset angles caused an expansion of 0.73 ± 0.42 sec in the silence period. Several studies reported similar results when investigating the effect of factors such as fatigue [16, 24], and prolonged cyclic flexion [25-26] for the lumbar spine. The early onset of the silent period indicates that fatigued neck extensor muscles are not able to maintain spine stability and therefore shift the load sharing sooner to the passive structure during flexion phase [16, 32] . The delayed offset of the silent period has been attributed to the increased contribution by the deep cervical muscles [33] .

Clearly, the results of this study showed that the neck extensor muscle fatigue modulates the FRP parameters and may challenge the cervical spine stability requirement. The fatigue induced changes in the FR parameters observed in this study could be used as the valuable markers to evaluate altered neuromuscular function and cervical spine MSDs development.

5. Conclusions

The results of this study showed that neck extensor muscular fatigue modulates the FR parameters by reducing the FRR and increasing the myoelectric silence period. These changes in the FR parameters suggest that cervical spine stability may be compromised by the degraded force generating capacity of the fatigued muscles and increased load-sharing by the passive cervical stabilizing structures.

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