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Cervical flexion–relaxation response to neck muscle fatigue in males and females

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ABSTRACT

In this study the effect of muscle fatigue on the cervical spine flexion–relaxation response was studied. Twenty healthy participants (10 males and 10 females) were recruited for data collection. The Sorenson protocol was utilized to induce neck muscle fatigue. Surface electromyography and optical motion capture systems were used to measure neck muscle activation and head–neck posture, respectively. A post-fatigue reduction in the Flexion–Relaxation Ratio (FRR) and higher FRR for females compared to males were observed. A post-fatigue decrease was also observed in the onset and offset angles resulting in an expansion of the myoelectric silence period. Gender had no effect on the onset and offset angles of the silence period. Post-fatigue shift in the onset and offset angles and the expansion of the silence period indicate an increased contribution by the passive viscoelastic tissues in stabilizing the cervical spine under fatigued condition.

1. Introduction

The work-related musculoskeletal disorders (MSDs) of the neck or cervical spine put a substantial burden on the health and economics in many industrialized countries. Recent U.S. Bureau of Labor Statistics (BLS) data indicate 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 (BLS, 2012). The symptoms of neck pain often last for prolonged periods of time and reoccurrence is observed for 50–80% of people within five years after the first occurrence (Côté et al., 2008). It is also estimated that about 67% of people suffer neck pain at some point in their life (Côté et al., 2004).

The etiology of neck or cervical spine MSDs is believed to be multidimensional, with physical work demands, psychosocial stress, and individual characteristics being the major contributing factors. Among the physical demands, work-related exposures such as sustained static postures, sub-maximal repetitive and forceful arm exertions are consistently identified as possible risk factors for cervical spine MSDs. Several studies have shown that the use of static and awkward head–neck postures leads to the fatigue of neck extensors (Finsen, 1999; Schüldt et al., 1986; Szeto et al., 2002). Repetitive arm and neck exertions are also known to contribute to the fatigue of the neck muscles (Chowdhury et al., 2013; Hagberg, 1981; Hansson et al., 1992). Some studies have also shown an active contribution by the neck muscles during forceful arm exertions leading to the fatigue (Kimura et al., 2007; Nimbarte, 2014; Nimbarte et al., 2012, 2013; Troiano et al., 2008).

Among the individual characteristics, gender has been consistently identified as a non-modifiable risk factor of MSDs of the neck (Hogg-Johnson et al., 2008). A higher prevalence of work-related neck pain was reported among females than males in several studies. In the United States, one year prevalence of neck pain among the general population was 40% for females compared to 29% for males (Bovim et al., 1994). A similar trend of higher prevalence of neck pain among females was also reported in the studies performed among Dutch, Swedish, and Japanese populations (Andersson et al., 1996; Guo et al., 2004; Picavet and Schouten, 2003). A higher prevalence of work-related neck pain for females was also reported in different working populations. Cagnie et al. (2007) reported an annual prevalence of 54.7% and 38.3% for females and males, respectively, among office workers. Fernandes et al. (2011) reported higher neck MSDs among females compared to males in a Brazilian plastics industry. Skov et al. (1996) reported a much higher prevalence of neck pain among the female (76%) sales workers compared to their male (54%) counterparts.

The muscle fatigue generated by work-related exertions and its interaction with gender may affect the biomechanical stability of the cervical spine. A less stable spine can be both a cause and

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consequence of spinal pain. Spinal stability is usually achieved through highly coordinated interactions of active and passive components of the neuromuscular system (Granata and Gottipati, 2008; Panjabi, 1992). The Flexion–Relaxation Phenomenon (FRP) explains the synergistic load sharing between these components. For the cervical spine, during head flexion, the cervical extensors gradually increase 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 forces sufficient to offset the effect of gravity, resulting in a reduced activation of the extensors (Meyer et al., 1993).

FRP in the cervical spine was first reported by Meyer et al. (1993). Consequently, other studies have evaluated the effect of factors such as load applied to the head, load carried using a backpack, trunk posture, computer use, and speed of movement on the load sharing between the active and passive tissues using cervical FRP (Lee et al., 2011; Pialasse et al., 2009, 2010; Yoo et al., 2011). A diminished FRP in individuals with symptoms of neck pain compared to asymptomatic healthy controls has also been observed in previous studies (Maroufi et al., 2012; Murphy et al., 2010). The main purpose of the current study was to quantify the post-fatigue changes in the stability of the cervical spine using the FRP. In addition, the role played by gender in the flexion–relaxation response of cervical spine due to the fatigue was also studied.

2. Methods

2.1. Participants

Twenty healthy adult participants (10 males and 10 females) were recruited to participate in this study (Table 1) from a pool of university students by posting advertisements on notice boards across the campus. The primary inclusion criteria required that the participants were free from any type of musculoskeletal, degenerative, or neurological disorders and had no history of neck, shoulder, and back injury or notable pain that required medical care over the last twelve months. All the participants gave their informed, written consent according to a protocol approved by the local Institutional Review Board.

2.2. Experimental protocol

A lab-based study was performed to study the effect of neck muscle fatigue on the cervical FRP. Neck muscle fatigue was induced according to the Sorensen fatigue protocol (Lee et al., 2005). Each participant lay prone on a table with arms to their sides and shoulders (acromion) level with the edge of the table (Fig. 1). The head and neck segments were exposed to gravitational forces to induce the neck muscle fatigue. A subjective scale (Borg CR-10 discomfort scale) was used to continuously monitor participant discomfort during the Sorensen protocol. The Sorensen protocol was discontinued when a score of 8 on the Borg scale was reached to prevent the risk of excessive fatigue or possible injury.

To study effect of fatigue on the cervical FRP, at least 3 head flexion–extension trials were recorded for each participant before and after the completion of the Sorenson protocol. These trials were performed in a seated posture. The upper body of the participants was stabilized in a seat using a four-point harness. Each head flexion–extension trial consisted of four phases (Fig. 2): (1) maintain neutral head–neck position for approximately 2 s; (2) fully flex the neck with the goal of approximating the chin to the upper chest (manubrium) within 5 s; (3) maintain full flexion for 5 s; (4) extend neck back to the neutral position within 5 s. A metronome with an audible tone (1 beat/s) was used to precisely control participants' movement during the different phases.

Table 1
Participants' demographic data.

Gender	Age (year)	Height (cm)	Weight (kg)
Female	29.1 ± 3.9	162.9 ± 6.3	56.2 ± 7.7
Male	24.1 ± 2.4	175.6 ± 6.3	70.5 ± 7.6
Total	26.6 ± 4.2	169.3 ± 9.2	63.4 ± 10.7

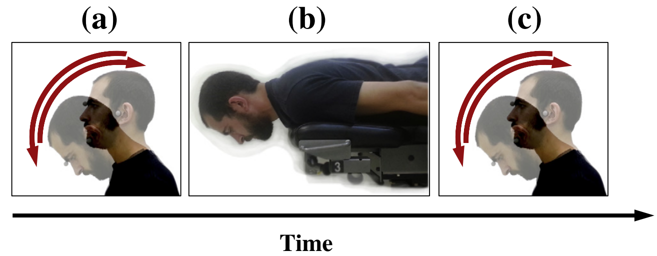

Fig. 1. Sequence of activities performed during the data collection: (a, c) head flexion–extension trials performed pre- and post-fatigue; (b) posture used during the Sorenson protocol to induce the neck muscle fatigue.

2.3. Instrumentation

The activity of the neck extensors during the Sorenson protocol and FRP trials was recorded using a Bagnoli-16 desktop surface electromyography (EMG) system with parallel bar-active surface electrodes (Delsys Inc., Boston, USA). The CMRR for the electrodes is 92 dB with input impedance greater than $10^{15}\ \Omega$. Two surface electrodes were placed bilaterally on the neck at the C4 level. The C4 level was determined as 2.5 times the distance between the C6–C7 vertebrae above the C7 level. The electrodes were placed parallel to the muscle fiber (approximately 35° to the vertical line between C7 and C4) (Nimbarte et al., 2010). The skin was prepared for electrode placement by shaving (if needed) and cleaning with 70% alcohol pads.

Head–neck kinematic data during the FRP trials were recorded using an eight-camera optical motion-capture system (Vicon Motion Systems, Oxford, UK). A set of three retro-reflective markers (14 mm in diameter) was used for the data collection. One marker was placed on the glabellas bone in the forehead area and the other two markers were placed on each side of the head at the proximal aspect of temporomandibular joint (TMJ). Vicon Nexus 1.8.1 software was used to record the kinematic as well as the EMG data. EMG data streams were synchronized with the motion data by acquiring the analog EMG data using a Vicon ADC (analog-to-digital converter) screw terminal box. The EMG and kinematic data were sampled at a rate of 1000 Hz and 100 Hz, respectively.

2.4. Data analysis

The EMG data recorded during the Sorenson protocol and the head flexion–extension trials were demeaned and full-wave rectified. The full-wave rectified EMG data were low pass filtered at 4 Hz using a fourth-order Butterworth filter to form a linear envelope (Burnett et al., 2007).

The endurance time during the Sorenson protocol varied between the participants. In one previous study, data recorded during the first minute were used in the analysis (Descarreaux et al., 2008). We believe that the data recorded during the middle part of the Sorenson protocol provide a better representation of the neuromuscular system's physiological status due to its adaptation to the prescribed exertion than the start or the end