Journal of Electromyography and Kinesiology 23 (2013) 1183–1189

Contents lists available at SciVerse ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Gender differences in neck/shoulder muscular patterns in response to repetitive motion induced fatigue

Larissa Fedorowich, Kim Emery *, Bridget Gervasi, Julie N. Côté

McGill University, 475 Pine Avenue West, Montreal, Quebec H2W 1S4, Canada
Michael Feil and Ted Oberfeld, Canada
CRIR Research Centre, Jewish Rehabilitation Hospital, 3205 Alton Goldbloom Place, Laval, Quebec H7V-1R2, Canada

ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form 13 April 2013
Accepted 6 June 2013

Keywords:
EMG
Variability
Mutual information
Functional connectivity
Endurance
Upper limb

ABSTRACT

Previous studies have associated amplitude and frequency characteristics of the electromyogram (EMG) to the risk of developing musculoskeletal disorders (MSDs) with repetitive tasks. However, few studies have investigated whether EMG variability and between-muscle activity characteristics may be associated with MSD risk. Twenty-six healthy volunteers (13 men, 13 women) performed a repetitive pointing task at shoulder height until scoring 8 on a Borg CR-10 scale. Electromyographic (EMG) signals were recorded from six neck/shoulder muscle sites. EMG amplitude (RMS), variability and mutual information (MI) among muscle pairs were computed. Muscle fatigue was evidenced by increased EMG RMS of four muscles (Upper Trapezius (UT): +17%; supraspinatus (SUPRA): +28%; middle deltoid: +13%; biceps brachii: +38%) and increased SUPRA variability. Correlations between minute 1 patterns and endurance time indicated that in women, initially high variability in UTR ($r = 0.79$) and SUPRA ($r = 0.71$) predicted higher endurance, whereas in men, initially low MI in LT–UT (-0.69) and in LT–SUPRA (-0.77) pairs predicted high endurance. Significant correlations suggest that variability and between-muscle patterns may be associated with fatigue and injury mechanisms, in a gender-specific way. Differing fatigue mechanisms between genders could help explain gender differences in injury mechanisms.

1. Introduction

Localized stress on skeletal muscles, caused by monotonous work and/or repetitive movement is recognized as a source of musculoskeletal disorder (MSD) development in the work environment (Jonsson, 1982). MSDs affect a large proportion of people, as a recent European survey found that 62% of the working population is exposed to repetitive upper extremity movements more than a quarter of their working day (Parent-Thirion et al., 2007). Prolonged static postures, repetitive movements and muscle fatigue have all been linked to discomfort in the neck and shoulder region (van der Windt et al., 2000). Enoka and Stuart (1992) define muscle fatigue as a decrease in functional capacity ensuing in increased perceived difficulty in maintaining force production. Previous research shows increases in a muscle's electromyographical (EMG) signal amplitude (e.g. root mean-square (RMS)) and decreases in its mean power frequency as fatigue develops during sub-maximal contractions (Vollestad, 1997). However, recent research suggests that other factors related to repetitive movements, such as creep in viscoelastic tissues, may also contribute to the observed changes in EMG signals (Solomonow, 2012).

Another physical characteristic previously linked to the presence of fatigue and of symptoms is motor variability. It is defined as the existing variability in sensorimotor actions (Newell and Slifkin, 1998), and can be quantified using standard deviation, median absolute deviation, co-efficient of variation or inter-quartile range (Madeleine, 2010; Mathiassen et al., 2003; Skurvydas et al., 2010). Studies on the effects of prolonged tasks on motor variability have reported conflicting results (Srinivasan and Mathiassen, 2012) with the majority suggesting increased motor variability. This has previously been interpreted as a search for new movement patterns to preserve task performance as fatigue develops (Côté et al., 2008, 2005; Forestier and Nougier, 1998; Fuller et al., 2011). On the other hand, studies have found task performance deterioration during prolonged tasks, suggesting a reduced ability to adjust some patterns, such that motor variability components could be task-specific (Huysmans et al., 2008). Finally, Moseley and Hodges (2006) previously showed that larger movement variability was associated with a higher probability of returning to normal postural strategies after experimental pain,

---

* Corresponding author. Addresses: Department of Kinesiology and Physical Education, Jewish Rehabilitation Hospital, Canada. Research Department, 3205 Alton Goldbloom Place, Laval, Quebec H7V-1R2, Canada. Tel.: +1 450 688 9550x4827.

E-mail address: kim.emery@mail.mcgill.ca (K. Emery).

1050-6411/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jelekin.2013.06.005

suggesting that individuals who display less variability may be at higher risk of developing injury.

In addition to individual muscle patterns, the way that muscles work together has also been previously suggested to be part of the fatigue and injury mechanisms. Mutual information (MI), which can be defined as the amount of functional or shared connectivity between two muscles, is another statistical method of quantifying co-ordination patterns between muscles by accounting for both linear and non-linear relationships between two EMG time series (Jeong et al., 2001; Kojadinovic, 2005). Only few studies have used this approach to study intermuscular patterns. In a study of the trapezius muscle in males during dynamic and static contractions, Madeleine et al. (2011) found higher levels of functional connectivity or normalized MI (NMI) between the upper–middle, and middle–lower trapezius muscle pairs post-exercise compared to pre-exercise. However, during a repetitive box-folding task, no changes in functional connectivity were observed with time (Johansen et al., 2012), such that the effects of repetitive movements on NMI of corresponding muscles remain unclear.

Several previous studies have highlighted gender differences in the prevalence of neck/shoulder disorders, which is generally higher in women (Côté, 2012). However, higher fatigability is generally reported in men (Hicks et al., 2001; Hunter, 2009), such that the injury mechanisms may differ between the genders (Côté, 2012). Moreover, few studies have assessed possible gender differences in motor variability and inter-muscle patterns. Women were found to produce less variance in an elbow force production task (Svendsen and Madeleine, 2010) and less lower body variability in a treadmill locomotion task (Barrett et al., 2008). Moreover, in a study of experimental shoulder pain, females were found less able to rearrange shoulder muscle activity as much as males and also reported higher extents of perceived pain (Falla et al., 2008). Gender differences have also been observed in activation patterns of primary and secondary muscles during an isometric task performed at 50% maximum force (Anders et al., 2004) with women showing more activation of accessory muscles and less activation of primary muscle groups than men. Moreover, during a repetitive box-folding task, higher connectivity (NMI) was measured in females in the upper–middle, and upper–lower trapezius muscle pairs (Johansen et al., 2012). Taken together, these studies are inconclusive as to whether there are gender differences in muscle activity patterns, and if there are, whether these differences include characteristics other than the ones previously measured in most studies based on EMG analysis.

In summary, few studies that account for muscle characteristics of variability and functional connectivity have been conducted but suggest that these aspects could help explain fatigue and injury mechanisms, as well as gender differences therein. Therefore, the aim of this study was to describe the within and between-muscle changes occurring with fatigue resulting from the performance of a repetitive task targeting neck/shoulder fatigue. We hypothesized that specific muscular patterns would predict endurance and that there would be gender differences in muscular strategies developed to adapt to fatigue.

2. Methods

2.1. Participants

Thirteen men and 13 women were recruited as a convenience sample to participate in this study (see Participant characteristics, Table 1). Volunteers were excluded if they had been diagnosed with an injury or disorder, had reported pain, or had displayed reduced range of motion in the neck and/or shoulder area during the year prior to the experiment. At arrival, all participants provided informed consent by signing forms approved by the Research Ethics Board of the Centre for Interdisciplinary Research in Rehabilitation (CRIR) of Greater Montreal. All were right-handed.

Table 1
Participant characteristics. $P < 0.05$ indicates a significant gender difference.

Characteristic	Men	Women	*T*-test
Age (years)	27.6 (±11.7)	29.3 (±11.3)	$p = 0.137$
Height (cm)	172.7 (±6.6)	161.8 (±6.0)	$p = 0.001$
Weight (kg)	81.2 (±10.9)	62.6 (±13.0)	$p = 0.0004$

2.2. Data acquisition

Upon arrival of the participant, Ag/AgCl disposable surface electrodes (Ambu™, Denmark) were placed on alcohol cleaned and shaven skin of six muscle sites. The electrodes were applied with a 3 cm center-to-center distance, parallel to the muscle fibers on each of the fallowing sites: Upper Trapezius (UT: 20% medial to midpoint between the acromion and C7 spinous process), Middle fibers of the Trapezius (MT: 20% medial to midpoint between the medial border of the scapula and T3 spinous process), Lower Trapezius (LT: 33% medial to midpoint between inferior angle of the scapula and T8 spinous process), Supraspinatus (SUPRA: centered along the upper border of the spine of the scapula), Middle Deltoid (MD: midline of the lateral surface of the arm, ¼ of the distance between the acromion and the elbow) and Biceps Brachii (BIC: midpoint between the acromioclavicular and elbow joint) (Basmajian and Blumenstein, 1980; Madeleine and Madsen, 2009). EMG data was recorded using a Telemyo 900 (Noraxon, USA) measurement system with a sampling frequency of 1080 Hz. Once the electrode set-up was complete, participants were directed to perform the fatigue protocol.

In order to perform the repetitive pointing task (RPT) to fatigue, two touch-sensitive targets (response time of 130 ms (Quantum Research Group Ltd.)) were positioned at shoulder height in front of the midline of the participant, one distal at 100% of arm's length, and one proximal at 30% of arm's length (Fuller et al., 2009). Participants were instructed to move their arm in a horizontal plane, keep their moving elbow above a mesh, oval-shaped barrier positioned under the elbow trajectory and alternate touches to each target at 1 Hz movement rhythm, following a metronome. EMG data were collected for 30 s at the end of every minute, after which participants were asked to rate their self-perceived shoulder exertion on a 0–10 Borg CR-10 scale (Borg, 1982). The RPT continued until the participant was either no longer able to maintain the 1 Hz rhythm, the elbow made contact with the mesh barrier, or they reported a perceived exertion of 8 or higher out of 10 on the Borg CR-10 scale (Côté et al., 2008). Participants were not aware of these stoppage criteria.

2.3. Data analysis

Time to fatigue was determined as the number of minutes the task was performed for each participant. To perform EMG data analysis, only the 30 s collected during the first and the last minutes of the RPT were used for analyses and are defined as the no-fatigue and fatigue trials, respectively. All EMG data were filtered using a dual-pass 4th-order Butterworth bandpass filter (20–500 Hz) and heartbeats were removed by identifying one reference beat per trial, and cross-correlating it with the remaining signals to remove heartbeats from all 6 muscle signals. Signals were then full-wave rectified. Root-mean-squared (RMS) amplitude values were calculated over 30 1-s windows taken from the no-fatigue and fatigue trials of each muscle signal and all EMG