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Adaptations to isolated shoulder fatigue during simulated repetitive work. Part I: Fatigue

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ABSTRACT

Upper extremity muscle fatigue is challenging to identify during industrial tasks and places changing demands on the shoulder complex that are not fully understood. The purpose of this investigation was to examine adaptation strategies in response to isolated anterior deltoid muscle fatigue while performing simulated repetitive work. Participants completed two blocks of simulated repetitive work separated by an anterior deltoid fatigue protocol; the first block had 20 work cycles and the post-fatigue block had 60 cycles. Each work cycle was 60 s in duration and included 4 tasks: handle pull, cap rotation, drill press and handle push. Surface EMG of 14 muscles and upper body kinematics were recorded. Immediately following fatigue, glenohumeral flexion strength was reduced, rating of perceived exertion scores increased and signs of muscle fatigue (increased EMG amplitude, decreased EMG frequency) were present in anterior and posterior deltoids, latissimus dorsi and serratus anterior. Along with other kinematic and muscle activity changes, scapular reorientation occurred in all of the simulated tasks and generally served to increase the width of the subacromial space. These findings suggest that immediately following fatigue people adapt by repositioning joints to maintain task performance and may also prioritize maintaining subacromial space width.

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1. Introduction

Numerous industrial jobs consist of low load, repetitive tasks, which have been identified as increasing risk for developing workplace injuries (Nordander et al., 2009). Along with tissue damage, altered movement patterns have been observed with repetitive work in animal models. Movement pattern changes have the potential to increase, or decrease, exposure over time, and also provide opportunity for rest and recovery (Barbe et al., 2003; Coq et al., 2009; Elliott et al., 2008). The mobility afforded by the human shoulder and the upper extremity may allow workers opportunities to use kinematic and muscle recruitment strategy changes to adapt to the demands of repetitive work, especially when compromised with fatigue.

The shoulder complex achieves its large range of motion through the simultaneous motion of its three joints (Inman et al., 1944). Vital to maintaining this range of motion is proper motion of the scapula (Inman et al., 1944; Picco et al., 2010; van der Helm et al., 1995). Scapular position also impacts the space between the acromion and the humeral head that encompasses rotator cuff tendons, known as the subacromial space (SAS) (Banas et al., 1995). The SAS is highly variable between individuals and affected by arm position, scapular rotation, and muscle activity (Banas et al., 1995; Chopp and Dickerson, 2012; Graichen et al., 2005). Muscle attachment sites on the scapula cause its orientation to be affected by changes in muscle activity patterns and fatigue (Ebaugh et al., 2005). For example, a fatiguing external rotation protocol has been shown to lead to increased scapular external rotation, upward rotation, and decreased posterior tilt during humeral elevation (Ebaugh et al., 2006a,b; Tsai et al., 2003). The SAS can also be affected with rotator cuff muscle fatigue and humeral head migration during humeral elevation (Chen et al., 1999; Chopp et al., 2011).

Repetitive work and muscle fatigue can lead to other kinematic changes in the upper extremity as well. Following fatigue protocols, scapulothoracic and glenohumeral changes have been found to be sensitive to elevation angle (Ebaugh et al., 2006a,b; Tsai et al., 2003). Adaptations have also been observed in more complex tasks involving multiple joints and specific performance demands. For example, with repetitive pointing, participants changed their wrist and elbow movements to compensate for altered shoulder position (Fuller et al., 2009). People appear to prioritize

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performance of endpoint location with compensations made via greater variability in movement trajectories in other axes, changes in endpoint velocity, movement time and kinematics (Bosch et al., 2012; Fuller et al., 2011; Luger et al., 2015). Many of these studies have demonstrated that movement changes occur as muscle fatigue develops during repetitive work, how they react to a strong fatigue stimulus remains unknown.

Allowing workers to maintain performance and quality standards as well as understanding adaptations during workplace tasks is important for worker health and applications such as job design. An early study found that experienced carpenters were able to maintain performance during simulated sawing, drilling and hammering tasks despite completing a fatigue protocol; however their kinematics were not monitored, so the strategies used to maintain task performance are not known (Hammarskjiild & Harms-Ringdahl, 1992). Other investigations of repetitive hammering and sawing have observed multi-joint changes that allowed participants to maintain performance following a fatigue protocol (Côté et al., 2002, 2005). During a sawing task there was a large change in elbow range of motion that was offset by a number of concurrent small changes in other joints (Côté et al., 2002). Changes in movement patterns may provide objective signs of reduced capacity. Given that changes in posture are often observable, they could be used as indicators of fatigue in an occupational setting. Previous work in our laboratory has evaluated changes to EMG and kinematics during one hour of simulated repetitive work and found that adaptations occurred before signs of muscle fatigue (Ebata, 2012). Muscle fatigue development while performing low load tasks can be time consuming and thus fatigue protocols can be used to accelerate the development of muscle fatigue. Understanding these strategies following a fatigue protocol leads to the purpose of this investigation, which was to examine the muscular and kinematic adaptation strategies that develop in response to isolated muscle fatigue while performing simulated repetitive work.

This is the first of a two-part communication of our investigation aimed at understanding the immediate and longer-term adaptations to fatigue. This paper will focus on the immediate effects of fatigue in the first 8 min of repetitive work following a fatigue protocol. The companion paper will examine the response over one hour of repetitive work (McDonald et al., 2016). We hypothesized that after fatiguing the anterior deltoid; participants would be able to maintain performance through changes in muscle recruitment and kinematics of the upper extremity and trunk. The kinematic changes should act to reduce the shoulder moment demands and muscle activity will support the mechanical needs at the shoulder.

2. Methods

2.1. Participants

Twelve right-hand dominant men, free from upper limb or shoulder pathologies in the past year were recruited from the university population. The study was approved by the Hamilton Integrated Research Ethics Board (HIREB). Participants provided written consent, age (20–24 years) and anthropometric measurements including mass (76.5 ± 8.5 kg), height (177.9 ± 6.8 cm), umbilicus height (108 ± 5 cm), and acromioclavicular height (148 ± 6 cm).

2.2. Instrumentation

Eleven cameras (Raptor-4, Motion Analysis Corporation, Santa Rosa, CA) sampled 26 reflective markers (at 100 Hz) placed on specific anatomical landmarks of the pelvis, thorax, and right upper extremity (Wu et al., 2002, 2005). A scapular tracker with 4 reflective markers was affixed to the skin over the spine of the scapula and the acromion and used to capture subcutaneous scapular movements (Fig. 1) (Karduna et al., 2001; Parel et al., 2013). Temporary markers were placed on the skin on the inferior angle and root of the scapular spine and were removed after relationships were established with static calibration trials.

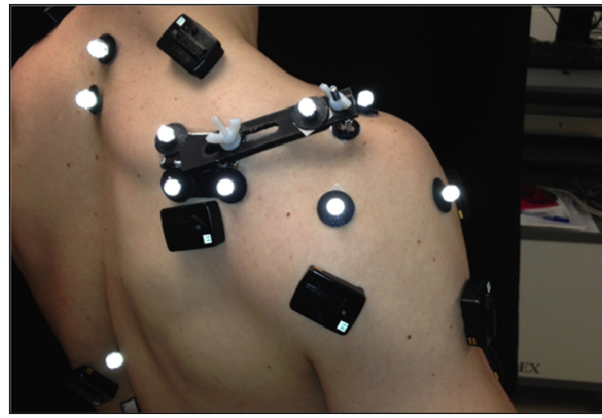

Fig. 1. A scapular tracker with four reflective markers was used track the three-dimensional motion of the scapula. The hinge conformed to the mid portion of the scapular spine and the adjustable arm extended to the area above the postero-lateral aspect of the acromion process. The footpad was affixed to the skin over the acromion and conformed to the angle of the acromion with a ball and socket joint (modeled after Karduna et al., 2001).

Surface electromyography (EMG) of 14 muscles was recorded using silver-contact wireless bipolar bar electrodes with fixed 1 cm inter-electrode spacing (Trigno, Delsys Inc., Natick, MA, USA). Muscles on the right side included pectoralis major (sternal and clavicular head), latissimus dorsi, serratus anterior, infraspinatus, anterior deltoid, middle deltoid, posterior deltoid, biceps brachii, triceps brachii. The upper and lower trapezius were monitored bilaterally. EMG signals were differentially amplified (CMRR > 80 dB, input impedance 10^{15} Ω), band-pass filtered (20–450 Hz), sampled at 2000 Hz and were converted with a 16-bit card with a ±5 V range. Prior to electrode placement, sites were shaved and skin scrubbed with isopropyl alcohol. Electrodes were placed parallel to muscle fibers (with guidance from Perotto & Delagi, 2005). Maximum voluntary exertions were performed to elicit maximal activity from each muscle. Each of the 14 tests were repeated twice and the peak muscle activity across all tests was used to normalize EMG data (Hodder & Keir, 2013; Perotto & Delagi, 2005).

2.3. Simulated work protocol

Participants completed two blocks of simulated repetitive work separated by an anterior deltoid focused fatigue protocol. Each work cycle was 60 s in duration. Twenty (20) cycles were completed before the fatigue protocol ("pre-fatigue") and 60 cycles were completed after the fatigue protocol ("post-fatigue"). Simulated work was performed at a workstation comprised of 4 tasks: (1) handle pull (2 kg, 10 repetitions), (2) cap rotation (3 clockwise & 3 counter-clockwise repetitions), (3) 10 s anterior drill press (50% MVC), (4) handle push (2 kg, 10 repetitions) (Fig. 2). Tasks 1 and 4 were positioned above the umbilicus by one-half the vertical distance between the umbilicus and AC joint and tasks 2 and 3 were adjusted to this same vertical distance above the AC joint for each participant. Based on previous work from our laboratory, these tasks were selected as a sample of possible industrial tasks and the apparatus was positioned such that the completion

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