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Full Length Article

Upper body kinematic and muscular variability in response to targeted rotator cuff fatigue[☆]

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ABSTRACT

The rotator cuff muscles are prominent stabilizers of the shoulder and are vulnerable to muscle fatigue. Rotator cuff fatigue may result in subacromial impingement (SAI) through the superior translation of the humeral head. Scapular changes have been reported inconsistently, but may prevent SAI. The purpose of this study was to quantify changes in scapular kinematics, as well as muscle activity during glenohumeral motions following targeted rotator cuff fatigue. Ten healthy men completed four planar glenohumeral motions (cross-flexion, frontal, scapular, and sagittal plane elevation) prior to and immediately following a rotator cuff fatigue protocol on two separate days. Scapular kinematics and muscle activity of thirteen muscles were recorded. Scapular protraction decreased significantly with fatigue during scapular plane elevation ($p < 0.001$; $\eta_p^2 = 0.74$). Although not significant, large effect sizes were found with decreased scapular protraction during elevation in the frontal ($p = 0.012$; $\eta_p^2 = 0.52$) and sagittal planes ($p = 0.007$; $\eta_p^2 = 0.58$), as well as decreased scapular medial rotation during cross-flexion ($p = 0.008$; $\eta_p^2 = 0.56$). Between-subject variability (standard deviations from 2.3° to 14.5°) and within-subject day-to-day differences (upwards of 10° deviation in the opposite direction) were high among all kinematic changes following fatigue. Considerable day-to-day differences in scapular stabilizer muscle activity in response to fatigue were present. Due to the degrees of freedom at the upper extremity, individuals can employ a variety of compensatory strategies to fatigue. The variable compensatory strategies across the scapular stabilizers resulted in individual-specific scapular kinematic changes that could act as either impingement-sparing or impingement-promoting. The high variance in day-to-day differences within-subjects indicates that kinematic and muscular responses to fatigue may be adaptive within individuals over time.

1. Introduction

The rotator cuff is comprised of four muscles that actively stabilize the glenohumeral joint. One of the stabilizing roles of the rotator cuff is to pull inferiorly on the humeral head (Sharkey & Marder, 1995), increasing the subacromial space (SAS), the area located between the inferior surface of the acromion and the humeral head (Petersson & Redlund-Johnell, 1984). As the rotator cuff muscles act to maintain shoulder stability through most of the shoulder's range of motion (Lee, Kim, O'Driscoll, Morrey, & An, 2000; Michener, McClure, & Karduna, 2003), these muscles may be particularly vulnerable to fatigue during repetitive shoulder movement (Ebaugh, McClure, & Karduna, 2006a). Consequently, impaired functionality of the rotator cuff muscles due to fatigue may contribute

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[☆] Protocol approved by the *Hamilton Integrated Research Ethics Board (HIREB #09-548)*.

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to the high incidence of shoulder musculoskeletal disorders (MSDs) reported in the USA and Canada (U.S. Department of Labor and Bureau of Statistics, 2016; WSIB, 2016).

Altered upper extremity kinematics have been observed among individuals experiencing shoulder fatigue (Ebaugh et al., 2006; McQuade, Dawson, & Smidt, 1998; McDonald, Tse, & Keir, 2016; Tse, McDonald, & Keir, 2016), which is hypothesized to change the risk of shoulder MSDs due to fatigue. Prior investigations report two kinematic changes that could arise as a consequence of rotator cuff fatigue that can have implications with respect to the SAS: (i) superior humeral head translation and (ii) changes in scapular orientation. Following rotator cuff fatigue, the humeral head is consistently found to translate superiorly and reduce the SAS (Chen, Simonian, Wickiewicz, Otis, & Warren, 1999; Chopp, Fischer, & Dickerson, 2011; Teyhen, Miller, Middag, & Kane, 2008). As a consequence, the humeral head can compress tissues within the SAS, such as the rotator cuff tendons, otherwise known as subacromial impingement (SAI) (Neer, 1972). Unlike changes in the position of the humerus, scapular kinematic responses to fatigue may be protective by increasing the SAS (Chopp et al., 2011). However, prior investigations have found inconsistent results following rotator cuff fatigue, with scapular changes having the potential to increase or decrease the SAS (Chopp et al., 2011; Ebaugh et al., 2006; Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Tsai, McClure, & Karduna, 2003). The mixed results suggest that scapular compensations to rotator cuff fatigue may function as either “impingement-sparing” or “impingement-promoting”. It remains unknown whether these scapular changes are individually adaptive and whether individuals respond similarly when exposed to rotator cuff muscle fatigue on separate days.

Prior investigations examining the effects of muscle fatigue on kinematic strategies during repetitive simulated assembly work have observed a high degree of between-subject variability (McDonald et al., 2016; Tse et al., 2016). A large source of variability is hypothesized to be due to the complex multi-segment movements examined, which involve coordination across a number of degrees of freedom, thus can be performed in countless kinematic permutations. Consequently, individuals have several movement strategies available to compensate for fatigue, which can cause multiple simultaneous changes that may independently affect scapular orientation. For example, a decreased shoulder abduction angle alters the forces generated in the scapular stabilizing muscles due to the length-tension curve. Furthermore, fatigue induced from repetitive arm motion affects many muscles in addition to the rotator cuff group to varying levels (Ebaugh et al., 2006a). To reduce variability and confounding factors, a fatigue protocol targeting specific muscles and investigating simple, constrained motions appears optimal to isolate scapular changes and their potential to increase or decrease the SAS.

Recent evidence suggests that individuals experiencing fatigue exhibit redistribution of muscle activity across muscles as a means to compensate for fatigue (Ebata, 2012; McDonald et al., 2016; Tse et al., 2016). As shoulder muscles share similar functions during many upper extremity tasks (Escamilla, Yamashiro, Paulos, & Andrews, 2009), muscle redistribution strategies may be especially prominent at the shoulder complex. Examination of muscle activity may shed light into the kinematic adaptations to fatigue and help identify strategies to avoid SAI. The majority of investigations examining the effects of rotator cuff fatigue are limited by the lack of simultaneous EMG and kinematic measurements. One study found that individuals exhibited decreased lower trapezius activity simultaneously with increased scapular superior rotation during a diagonal shoulder movement following an external rotation fatigue protocol (Joshi et al., 2011). As the lower trapezius functions to superiorly rotate the scapula, the decreased activation was unexpected and highlights the importance of recording a comprehensive group of shoulder muscles to examine EMG and kinematic changes together.

The purpose of this study was to quantify changes in kinematics and muscle activity during planar glenohumeral motions following a rotator cuff fatigue protocol targeting the infraspinatus muscle. Theoretically, this should allow an isolated response to rotator cuff fatigue by keeping humeral motion constant thus minimizing indirect extraneous effects on scapular motion. Scapular orientation may then be assessed to examine its potential for change in SAS width, as well as associated compensatory muscular strategies. A secondary purpose of the study was to assess the between-day repeatability of the kinematic and muscular responses to rotator cuff fatigue within individuals. It was hypothesized that participants would display altered kinematics and muscle activity following the fatigue protocol, with a high degree of variability expected between individuals. The kinematic and muscular responses to fatigue were hypothesized to be relatively consistent within participants across days.

2. Methods

2.1. Participants

Ten healthy right-hand dominant males from the university population with a self-reported absence of shoulder pain and injury within the previous year were recruited for this study (21.6 ± 1.6 years; 180.2 ± 5.1 cm; 78.4 ± 12.9 kg). The Hamilton Integrated Research Ethics Board approved this study and all participants provided written informed consent. Each participant performed the experimental protocol on each of two days. Visits were separated by at least seven days to minimize any carryover effects from muscle fatigue between visits.

2.2. Instrumentation

A wireless surface electromyography (EMG) system (Trigno™ Wireless Systems, Delsys, MA, USA) recorded activities from thirteen right shoulder muscles. The EMG signals were recorded using a differential amplifier (CMRR $>$ 80 dB, input impedance $10^{15}\,\Omega$), band-pass filtered (20–450 Hz), and sampled at 2000 Hz. Prior to electrode placement, the skin overlying the muscle belly was shaved and scrubbed with isopropyl alcohol. Electrodes were oriented parallel to the direction of the muscle fibres. Activity was recorded