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Shoulder muscle activation and fatigue during a controlled forceful hand grip task

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ABSTRACT

Purpose: Reliable electromyographic evaluation of the shoulder in common painful conditions is a major challenge due to a reduced range of movement and pain-related muscle inhibition. This study investigates the use of a hand grip task for the assessment of shoulder muscle activation.
Methods: Muscle activity and fatigue for supraspinatus and infraspinatus muscles were measured in 16 healthy controls using fine-wire electrodes during a controlled gripping task at 50% of maximum voluntary contraction, in a standardized sitting and arm position. Changes in muscle activity and fatigue were measured by the time-slope of root mean square amplitude and median frequency, respectively.
Results: A significant positive amplitude slope ($p < 0.01$) was found for both supraspinatus and infraspinatus, indicating that the task resulted in increasing muscle activity. Judging by the median frequency slope, there was no sign of fatigue progression.
Conclusion: A standardized hand grip task in a neutral position activates key rotator cuff muscles. This might provide a method for electromyographic assessment of shoulder girdle muscles which avoids problems due to pain-related limitation of movement, and might be useful in the development and monitoring of shoulder rehabilitation strategies.

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1. Introduction

Shoulder pain is common with a 6–11% prevalence in the under-fifties and 16–25% in the elderly (Bjelle, 1989). It causes significant functional incapacity for affected individuals, placing significant demands on social care resources (Jones et al., 1995). Although activities causing high shoulder loads such as heavy industrial work, arm elevation, repetitive muscle strain, hand load (Herberts and Kadefors, 1976; Herberts et al., 1984; Jarvholm, 1990; Sigholm et al., 1984), and static muscle load (Hagberg et al., 1995) have been identified as potential risk factors (Buckle, 1997), systematic reviews have not established the causal links directly (Andersen et al., 1976; van der Windt et al., 2000). The interrelationship of hand activity with shoulder muscle activity is the subject of the present study.

Since Inman's pioneering work, EMG has been a powerful tool for analyzing muscle activity in relation to shoulder joint motion (Inman et al., 1996). The rotator cuff muscles, especially supraspinatus (SSP) and infraspinatus (ISP), are of interest because of their key multifunctional roles in shoulder stability and movement. They are exposed to potential stress during occupational and manual work, and in a variety of sporting activities (Escamilla and Andrews, 2009). In a study of light manual work, the greatest change of shoulder muscle EMG activity was in SSP and ISP (Sporrong et al., 1998). During overhead manual work Kadefors et al. (1976) and Herberts and Kadefors (1976) found heavy static loading in the shoulder muscles, particularly in SSP. EMG studies found that SSP showed earliest signs of fatigue (Hagberg, 1981). Hand loading also increases intramuscular pressure in SSP and especially ISP (Jarvholm et al., 1989, 1991). Sporrong et al. (1995) used EMG to study the effects of hand activity on SSP and ISP, reporting up to 10% increased activity of both during a forceful gripping task, but there was no evidence of localized shoulder muscle fatigue during isometric hand grip (Sporrong et al., 1995, 1996).

Hand muscle activity, especially gripping, is an essential kinesiologic part of many work- and sport-related activities which can contribute to upper limb disorders. Stabilization of the glenohumeral joint (GHJ) by the SSP and ISP rotator cuff muscles is an essential prerequisite of hand grip activity. This interrelationship has both biomechanical and clinical implications. Direct EMG and biomechanical assessment of shoulder girdle muscles in common painful shoulder disorders (e.g. subacromial impingement and rotator cuff tears) is difficult and unreliable due to pain and

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consequent limitation of movement. Understanding how the shoulder muscles are activated during hand loading may yield insight into mechanisms of injury, supporting better preventative strategies and more effective rehabilitation.

The present study aimed to define the importance of hand activity for GHJ loading by using intramuscular fine-wire EMG to measure activity and fatigability of two key shoulder girdle muscles, SSP and ISP, during a gripping task.

2. Methods

Studies on the dominant arm of 16 healthy subjects (7 women and 9 men) with no history of upper limb musculoskeletal problems were undertaken as described below. A pilot study (Alizadehkhaiyat et al., 2007) established fine-wire electrode placement, noise reduction, reproducibility of measurements and data handling. Written informed consent was obtained from each subject and the study had approval from the local Research Ethics Committee. Grip strength was measured using a Jamar dynamometer (Biometrics Ltd., E-LINK, Gwent, UK) in a standardized position. Subjects sat on a chair without armrests (back against the chair back, with hips and knees flexed at 90°, shoulders adducted and neutrally rotated, elbows flexed at 90°, forearm in 0° rotation and wrist in 0–30° of dorsiflexion) and squeezed the handle maximally for 3 s. The average of three measurements was taken as maximum voluntary contraction (MVC). Participants then exerted a constant 50% MVC, guided by feedback on a computer screen (Fig. 1). Recordings were performed for about 70 s from which the first and last 5 s were discarded before the analysis. EMG signals were recorded from SSP and ISP using bipolar intramuscular fine-wire electrodes (Disposable Paired Hook Wire Electrodes, Nicolet Biomedical, Division of VIASYS, Madison, USA). The electrodes were inserted into SSP and ISP using a hypodermic needle (Lee and DeLisa, 2000). Insertion points were approximately 1.5 cm above (SSP) and 2.5 cm below (ISP) the midpoint of the spine of the scapula. A silver/silver chloride surface electrode was placed on the bony prominence of the acromioclavicular joint as the ground electrode. This technique permits analysis of signals from deep muscles not accessible with surface electrodes (Inman et al., 1952; Kronberg et al., 1991; Pearl et al., 1992).

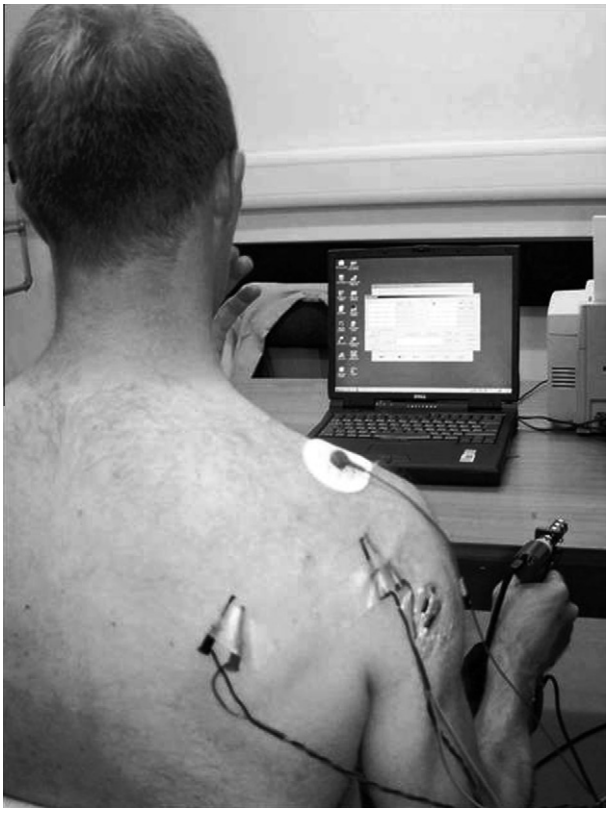

Fig. 1. Experimental setup and body position for grip strength measurement. The participant performs grip at 50% MVC with computer feedback while intramuscular EMG signals are recorded from supra- and infraspinatus on a separate computer.

Signals were recorded using a custom made amplifier (Department of Medical Physics and Clinical Engineering) with a common mode rejection ratio of $\geqslant$130 dB and a Biopac MP 100 system (Biopac Systems, Inc., Santa Barbara, CA, US) running *Acqknowledge* software. In each study multiple contractions (typically 3) were collected, and after a close visual inspection for baseline noise, potential motion artifacts and atypical spikes, the recording with the highest quality was taken for analysis.

The raw signal was differentially amplified at a sampling rate of 2000 Hz, and band-pass filtered (20–1000 Hz). For muscle activity measurement, signals were smoothed (2000 sample/window) and rectified (400 sample/window), and root mean square (RMS) amplitude was calculated in 5-s intervals (epochs). These epochs enabled a high time resolution while minimizing the variability in measured amplitude (Alizadehkhaiyat et al., 2007, 2009). Selection of epochs between 0.5 and 5.0 s does not significantly influence characterization of the temporal relationships of median frequency and amplitude during isometric muscle contraction (Hendrix et al., 2010). Furthermore, as the statistical characteristics of the MUAPs and noise are time-invariant and follow known distributions, analysis of signals in 5 s intervals, are long enough to obtain accurate estimates of the statistical parameters, but short enough that the parameters are not likely to change significantly during the interval (McGill and Marateb, 2011). Fatigue measurements used Fast Fourier transformation power spectrum analysis with Hamming window function on bins of 1024 data points; median frequency (MDF) calculated in 5 s intervals was normalized to the start value, and least-square linear regression fit was used to calculate the average rate (in %/min) of MDF decrease. A regression *t*-test was used to determine whether this slope differed significantly from zero. An independent samples *t*-test was used to compare EMG parameters between male and female subjects.

Descriptive statistics include the mean, standard deviation or standard error of measurement (as appropriate), and range. Normality tests (Shapiro–Wilks) confirmed a normal distribution of the data, so differences were assessed using a paired or unpaired *t*-test as appropriate, in SPSS.

3. Results

The mean ± SD age of participants was 40 ± 10 (range 26–59) years, mean body mass 71 ± 11 (range 56–85) kg and mean height 172 ± 13 (range 160–200) cm. Mean ± SD grip strength was 382 ± 105 N.

Descriptive statistics for RMS slope and starting values for SSP and ISP during grip at 50% MVC are given in Table 1. Changes in normalized RMS amplitude are shown graphically in Fig. 2. A significant positive RMS slope (different from zero at $p < 0.01$) was found for both SSP and ISP, indicating that muscle activity increased progressively during the task, with no significant difference between the two muscles. The corresponding MDF slope is presented in Table 1, and changes in MDF are shown graphically in Fig. 2. MDF did not show any shift toward lower frequencies during grip, the MDF slope being not significantly different from zero for both muscles. Independent samples *t*-test revealed no

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