Journal of Electromyography and Kinesiology 41 (2018) 139–146

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Can grip strength be used as a surrogate marker to monitor recovery from shoulder fatigue?

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ARTICLE INFO

Keywords:
Grip strength
Shoulder fatigue
Injury prevention
Return to play

ABSTRACT

Muscular fatigue impacts on normal shoulder function, which is particularly pertinent to throwing athletes. This study aimed to investigate the relationship between grip strength and shoulder muscle fatigue to evaluate the role of grip strength as a surrogate measure for upper limb performance. Twenty healthy participants were recruited. EMG was recorded from 15 shoulder muscles during different fatiguing contractions: an initial baseline recording (Fat-Baseline); after a shoulder exhausting exercise regime (Fat-Exhaustion); and after a 10 min rest period (Fat-Recovery). Grip strength was similarly measured in the same conditions. Grip strength differed significantly across the testing scenarios ($p = 0.012$– < 0.001). Greater fatigue was seen in anterior deltoid, middle deltoid, posterior deltoid and supraspinatus in the Fat-Exhaustion contraction as compared to the Fat-Baseline contraction ($p =$ < 0.001–0.043). Greater fatigue was seen during the Fat-Recovery contraction for the trapezius, serratus anterior and biceps brachii as compared to the Fat-Exhaustion contraction ($p = 0.008$–0.038). Grip strength decreased following an exhausting exercise protocol but recovered to baseline following a rest period. Conversely, EMG indices of fatigue did not recover. Additional fatigue was seen reflecting a reorganisation of movement strategy. Therefore, susceptibility to injury still exists if grip strength alone is used as a barometer of upper limb performance.

1. Introduction

The shoulder, owing to its limited osseous congruity, relies heavily on coordinated muscle activity for normal function (Lugo et al., 2008). Muscular endurance is an important component, especially during sustained tasks. Muscular fatigue, a time dependant process, occurs from the onset of a muscular contraction and is associated with external manifestations such as muscular tremor and pain. Fatigue differs from the failure point, the latter being the time at which a desired force output can no longer be maintained (De Luca, 1984).

Electromyography (EMG) is an accepted method of studying fatigue. EMG-driven indices of fatigue show a time-dependant change over the duration of muscular contraction, with a shift of the power spectrum towards lower frequencies (Dimitrova and Dimitrov, 2003; Hagg, 1992; Merletti et al., 1991). EMG has been used extensively to study shoulder muscle fatigue in both healthy subjects and patients with pathology. Weak and fatigue-susceptible muscles influence shoulder function by disrupting the normally balanced force couples (Bradley and Tibone, 1991; Glousman, 1993; Gowan et al., 1987). Adaptations in movement strategy occur in an attempt to maintain performance level, whilst protecting the fatigued (Andrade et al., 2016). However, changes in strength ratios (Andrade et al., 2016) and increases in proprioceptive errors (Weerakkody and Allen, 2017) that occur with fatigue can predispose to injury. This is particularly pertinent to high level overhead or throwing athletes, who can suffer with a range of shoulder injuries (Cowderoy et al., 2009; Gaber et al., 2014).

The recovery of an athlete after training induced muscle fatigue and return to play (RTP) following injury are two important current concepts. The link between increased training load, which induces muscle fatigue, and injury is well established (Jones et al., 2017). The identification of objective measures, which provide a reliable indication of recovery status within the training environment, would therefore be useful in allowing maximisation of training gains without disproportionately increasing the risk of injury. Objective measures are arguably more useful than subjective ones as the reliability of self-reported workload data has been questioned (Black et al., 2016). RTP decisions following injury can also be difficult due to the possible conflict of interest between multiple stakeholders, particularly within

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https://doi.org/10.1016/j.jelekin.2018.06.002
Received 6 February 2018; Received in revised form 4 June 2018; Accepted 5 June 2018

the professional athletic population (Shrier et al., 2014). In this scenario a surrogate measure for upper limb performance would similarly be helpful in informing RTP decisions (Clover and Wall, 2010).

Grip strength is associated with health-related quality of life and is a powerful predictor of disability, morbidity and mortality (Bohannon, 2008; Sayer et al., 2006; Syddall et al., 2003). It correlates highly with shoulder external rotation strength (Horsley et al., 2016) and it is known to activate key shoulder girdle muscles including supraspinatus and infraspinatus (Alizadehkhaiyat et al., 2011; Sporrong et al., 1995, 1996). Indeed a sustained grip contraction induces significant fatigue in a number of shoulder girdle muscles (Hawkes et al., 2015), the inference being that kinetic chain principles require a stable shoulder prior to activation of distal muscle groups. Measuring grip strength is straightforward and produces reliable results which are easy to record (Coldham et al., 2006). Furthermore, the equipment is both portable and affordable making its measurement convenient.

Recently there is increasing interest within elite sport rehabilitation in the use of grip strength as an objective measure of upper limb performance. However, at present, little is understood about the relationship between grip strength, shoulder muscle fatigue and subsequent recovery. This relationship must be defined if grip strength is to be considered a barometer for upper limb performance or recovery following either fatigue or injury. Therefore, the primary aim of this study was to evaluate the role of grip strength as a surrogate measure for monitoring upper limb recovery from fatigue following an exhausting exercise protocol. The hypothesis was that grip strength would correlate highly with EMG indices of fatigue: a decrease in grip strength was expected following an exhausting shoulder exercise protocol, with both grip strength and muscle fatigue then expected to recover following a rest period.

2. Methods

2.1. Participants

Twenty healthy participants including 10 males and 10 females with no previous history of shoulder pathology and a normal clinical examination were recruited into the study. Anthropometric details for the study group were as follows: mean age was 25.5 ± 7.5 yr, mean mass 72.8 ± 11.3 kg and mean height 172.0 ± 9.1 cm. The dominant arm was tested in all cases. The study received approval from the institutional research ethics committee and informed consent was obtained from all participants.

2.2. Strength measurements

Grip strength was measured using a Jamar dynamometer (Biometrics Ltd., UK). Subjects were tested seated on a chair with their hips and knees flexed to 90°; shoulder adducted; elbow flexed to 90°; and wrist and forearm in the neutral position. Maximal shoulder elevation strength in the scapula plane was measured using a shoulder Nottingham Mecmesin Myometer (Mecmesin Ltd., UK). Participants were tested in an upright position with feet shoulder width apart; shoulder elevated to 90° in the scapula plane (30° anterior to coronal plane); elbow extended; and forearm and wrist in neutral. Subjects were instructed to exert maximal effort over a 3 s period for all strength measurements. Three trials were performed and the average taken as the maximum voluntary contraction (MVC). Verbal encouragement was provided with participants being encouraged to exceed the previous measurement (Baratta et al., 1998).

2.3. EMG instrumentation

A Telemyo DTS system (Noraxon Inc., USA) was used for EMG signal acquisition. Analysis was performed off-line using the associated MR3 software (Noraxon Inc., USA). The activity in 15 shoulder girdle muscles was recorded. Surface electrodes were used for the anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), teres major (TM), upper fibres of latissimus dorsi (ULD), lower fibres of latissimus dorsi (LLD), pectoralis major (PM), teres major (TM) and biceps brachii (BB). The surface electrodes were disposable, pre-gelled Ag/AgCl bipolar electrodes with a conducting area of 10 mm diameter and inter-electrode distance of 20 mm (Noraxon Inc., USA). Electrodes were placed in accordance with accepted anatomical criteria (Cram et al., 1998; Prakash et al., 2006; Steenbrink et al., 2006). Cross talk was limited by using appropriately sized electrodes which were positioned parallel to the muscle fibres. Fine wire electrodes were used to record the activity of the supraspinatus (SSP), infraspinatus (ISP), and subscapularis (SUBS). Bipolar disposable hook wire electrodes (SPES Medica s.r.l. Battipaglia, Italy) were inserted aseptically into the muscle bellies via a single hypodermic needle (Kadaba et al., 1992; Noraxon, 2008). Signals were differentially amplified, digitised at a sampling rate of 3000 Hz and band-pass filtered in accordance with international guidance ((10–500)Hz for surface electrodes and (10–1500)Hz for fine wire electrodes). ECG contamination was removed using the adaptive cancellation algorithm pre-loaded within the MR3 software. Manual muscle testing was used to confirm electrode placement and the validity of the EMG signal. Those signals of poor quality, as determined by their signal to noise ratio, were excluded.

2.4. EMG testing protocol

Muscle fatigue was measured during a shoulder elevation isometric contraction performed in the scapula plane at 25% of the MVC. The testing position employed was the same as that used to measure shoulder elevation MVC (see Section 2.2). The contraction was sustained for 60 s or until failure (defined as a drop of > 5% force for > 5 s). Participants were provided with real time visual feedback via a PC screen displaying the Mecmesin Emperor Lite Force and Torque Data Acquisition Software (Mecmesin Ltd., UK). The software allowed participants to view their force generation and the target level as defined by their $MVC_{25\%}$. It also allowed any failure of the contraction to be identified by highlighting any drop in force of > 5% from target. An isometric contraction ensured a stable motor neurone pool, which is a necessary prerequisite for a contraction when studying fatigue (Hagg, 1992; Merletti et al., 1991). A submaximal contraction (ie $MVC_{25\%}$) is common to the majority of fatigue studies as it ensures comparisons between individuals are valid. In order to study the temporal change in the frequency throughout the contraction it has to be possible to maintain the contraction for a sufficient time period (ie 60 s). Low intensity contractions can result in variation in the motor unit pool as motor units are recruited and de-recruited throughout the contraction (Farina et al., 2006). Conversely, high intensity contractions cannot be maintained for a sufficient period of time. A $MVC_{25\%}$ was therefore chosen as an appropriate compromise, which has previously been accepted within the literature (Hawkes et al., 2015). Optimal rest time has not been defined for upper limb studies of this nature. A 10 min rest period was chosen as this has previously been evaluated in the literature (Lariviere et al., 2003).

Subjects undertook the fatigue contraction at 3 different time points. An initial recording was measured pre-exertion (Fat-Baseline). The second recording was made after subjects completed a shoulder exercise regime which was undertaken until exhaustion (Fat-Exhaustion). This exhaustion protocol involved 5 repetitions of shoulder elevation first in the sagittal plane (flexion) and then in the coronal plane (abduction) which were continuously repeated. The exercise was performed with a dumbbell in hand (the weight of which was set at 50% of shoulder elevation MVC rounded to the nearest 1 kg). Failure of this exhaustion protocol was defined as the inability of subjects to complete any further cycles of shoulder elevation. All subjects continuously performed this protocol until they reached the failure