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Spectral properties of electromyographic and mechanomyographic signals during dynamic concentric and eccentric contractions of the human *biceps brachii* muscle

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ABSTRACT

The purpose of this study was to describe and examine the variations in recruitment patterns of motor units (MUs) in *biceps brachii* (BB) through a range of joint motion during dynamic eccentric and concentric contractions. Twelve healthy participants (6 females, 6 males, age = 30 ± 8.5 years) performed concentric and eccentric contractions with constant external loading at different levels. Surface electromyography (EMG) and mechanomyography (MMG) were recorded from BB. The EMGs and MMGs were decomposed into their intensities in time–frequency space using a wavelet technique. The EMG and MMG spectra were then compared using principal component analysis. Variations in total intensity, first principal component (PCI), and the angle θ formed by first component (PCI) and second component (PCII) loading scores were explained in terms of MU recruitment patterns and elbow angles. Elbow angle had a significant effect on dynamic concentric and eccentric contractions. The EMG total intensity was greater for concentric than for eccentric contractions in the present study. MMG total intensity, however, was lower during concentric than during eccentric contractions. In addition, there was no significant difference in θ between concentric and eccentric contractions for both EMG and MMG. Selective recruitment of fast MUs from BB muscle during eccentric muscle contractions was not found in the present study.

1. Introduction

Electromyography (EMG) and mechanomyography (MMG) studies have described differences in MU control strategies during concentric and eccentric muscle actions. Greater EMG activation in concentric contractions compared to eccentric muscle actions has been reported in various muscles (Nakazawa et al., 1993; Linnamo et al., 2002, 2003). Moreover, it has been suggested that increases in muscle force were influenced more by motor unit (MU) recruitment than by changes in firing rate during concentric muscle contractions (Kossev and Christova, 1998; Coburn et al., 2005), whereas eccentric torque is primarily modulated through changes in motor unit firing rate of *biceps brachill* (Kossev and Christova, 1998) and *vastus medialis* (Coburn et al., 2006). Although it is controversial, some EMG studies examining MU recruitment during eccentric contractions have demonstrated a preferential recruitment of fast MUs over slow MUs (Nardone and Schieppati, 1988; Nardone et al., 1989). However, the effect of joint position during eccentric and concentric contractions was not clear. It has been shown that changes of joint angle associated with muscle length had a significant effect on the maximum muscle force production during isometric contractions (Kennedy and Cresswell, 2001; Mohamed et al., 2002). It is not clear how exactly surface EMG and MMG activities are altered by the joint angle during dynamic eccentric and concentric contractions. Measurement of muscle activation patterns during dynamic concentric and eccentric contractions in relation to the joint angle is important for understanding the basic mechanisms underlying motor control of limb movement, and very useful for constructing models of the neuromuscular control system (Stein et al., 1995; Rosen et al., 1999).

Therefore, the purpose of the present study was to describe and examine the variations in activation strategies of MUs in *biceps brachii* (BB) through a range of joint motions during eccentric and concentric contractions by using surface EMG, MMG, and a combination of wavelet analysis and principal component analysis (PCA) of the EMG and MMG spectra. Wavelet analysis that is well-defined in time and frequency resolution, with the non-linear scaling adjusted to the physiological response time of the muscle, was used to decompose EMG and MMG signals from dynamic concentric and eccentric

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contractions (von Tscharner, 2000; Qi et al., 2011). Then a quantitative method, principal component analysis (PCA), was used to describe the contribution of high- and low-frequency contents within the signal. It has been shown that the high- and low-frequency contents within the EMG and MMG are associated with the recruitment of fast and slow MUs, respectively (Wakeling and Rozitis, 2004; Hodson-Tole and Wakeling, 2007; Beck et al., 2008; Qi et al., 2011). Therefore, this type of analysis can be used to determine which types of muscle fiber are active during locomotion (Wakeling and Rozitis, 2004). The general hypotheses were (1) the elbow angle has an effect on MU recruitment patterns during concentric and eccentric contractions; (2) concentric and eccentric contractions may induce different motor control strategies which can be detected by differences in the time–frequency properties of the EMG and MMG signals.

2. Materials and methods

2.1. Participants

Twelve participants (6 males and 6 females with a mean age of 30 ± 8.5) with no history of any neuromuscular disorder gave informed written consent to participate in the experiments. The protocol and consent procedures were approved by Joint Research and Ethics Committee, Royal National Orthopaedic Hospital, UK.

2.2. Protocol

The participant sat in a chair with the left upper limb supported by a mechanical device. This support was designed to be highly adjustable so that it could to be correctly fitted to the dimensions of each participant relative to the shoulder articulation, keeping a 60° abduction (Fig. 1A) and with the forearm in a neutral position. The elbow angle was measured with an electrogoniometer (clinical goniometer fitted with a rotary optical encoder, ENA1J-B28-L00128, Bourns, Inc., Riverside, CA, USA). The elbow angle signal was provided to the participant as real-time feedback during the concentric and eccentric contractions.

Before the test, several practice trials were performed so that the participant could become familiarized with the test procedure. The maximum voluntary isometric contraction (MVIC) at elbow angle of 150° was determined first. One session of 80% maximum isometric contraction, performed at an elbow angle of 150°, was recorded to normalize the EMG and MMG signals later. A force transducer (Model LCCB-1K, OMEGA Engineering, Stamford, CT, USA) was used to measure the force generated from isometric contractions. A strap was positioned on the wrist, and connected to the force transducer mounted on the mechanical support. The maximum isotonic contraction was estimated from MVIC to determine the highest loads, the maximum voluntary isotonic contraction (MVTC) was then tried by participants from the best of three trials. Maximum voluntary contraction (MVC) was defined as the maximum loading the participant could overcome while moving through the range of motion. Participants performed a set of three concentric-eccentric contractions at each loading: 20%, 40%, 60%, and 80% maximum concentric load at 30°/s. Each dynamic contraction began at 150° elbow flexion and involved a 3-s concentric contraction from 150° to 60° (concentric, muscle shortening), followed by a 3-s eccentric contraction from 60° to 150° (eccentric, muscle lengthening) (Fig. 2). 3 min of rest was given between contractions of different loading.

Surface electromyographic signals (sEMG) (38 mm × 19 mm × 8 mm, two 12 mm disks, reference contact: 13 × 3 mm bar separating the sensors, inter-electrode distance: 17 mm, frequency response: 20–3500 Hz, Medical Grade Stainless Steel, Motion Lab Systems, Inc., Los Angeles, USA) and mechanomyographic signals (piezoelectric transducer, Model 1010, 23 mm diameter × 13 mm thick, 12.5 g weight, frequency response: 2.5–5000 Hz, GRASS technologies, Rhode Island, USA) were recorded on BB (Qi et al., 2011). These two sensors were close to the midline and centre of the muscle belly while maintaining zero contact between the two electrodes (Fig. 3). Sensors were fixed with Micropore tape (3M, St Paul, Minnesota, USA). The contact pressure may change during the dynamic contractions; a bandage was used to help keep a consistent pressure. The EMG and MMG signals were amplified (custom built EMG amplifier: Department of Medical Physics and Bioengineering, UCL, London, UK) and sampled at 5 kHz. The EMG, MMG, and electrogoniometer signals were recorded simultaneously with a 12-bit USB analogue to digital converter (DT9002, Data Translation, Malboro, Massachusetts, USA) during each concentric and eccentric contraction. For signal recording and visualizing signals for participant feedback, Agilent VEE Pro software (Version 6.0, Agilent Technologies, Santa Clara, California, USA) was used. All data analyses were performed off-line.

2.3. Signal processing

The EMG signals were resolved into their intensities in time–frequency space using wavelet techniques (von Tscharner, 2000). The method uses a filter bank of a series of non-linearly scaled wavelets (von Tscharner, 2000, 2002; Beck et al., 2008; Qi et al., 2011). The MMG signals were analyzed using a similar method as the EMG, but with a compressed series of wavelets (Qi et al., 2011). All signal processing was performed using custom programs written in Mathematica (version 6.0, Wolfram Inc., Champaign, IL, USA). Total intensity was given by summing the intensities over the selected wavelets (EMG: 10–350 Hz, k = 1–9; MMG: 3–90 Hz, k = 1–9). Total intensity is a measure of the time-varying power within the signal and is equivalent to twice the square of the root-mean-square. Movement artefacts are lower than 20 Hz in EMG (De Luca, 1979). For MMG, it has been suggested that 5 Hz high pass filters reduced the influence of body movements and gross limb displacement (Bajaj et al., 2002; Beck et al., 2005). The

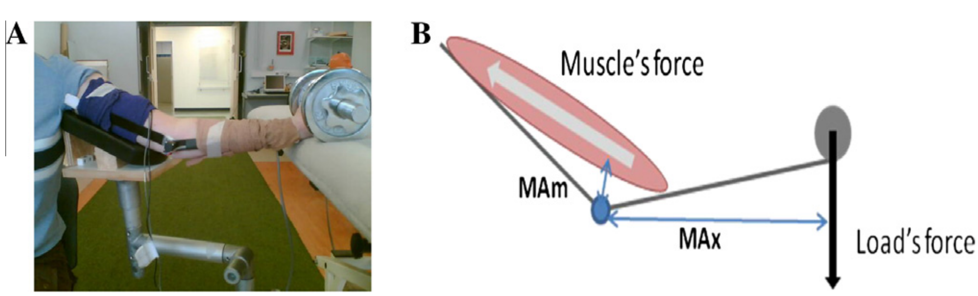

Fig. 1. (A) Concentric–eccentric contraction test. An electronic goniometry was attached at the fulcrum to measure elbow joint position. A bandage was used to ensure consistent pressure of the contact sensor; (B) schematic of a muscle that acts on a single joint. Muscle torque (Fm·MAm) as a function of muscle length associated with elbow angle.