Journal of Electromyography and Kinesiology 23 (2013) 1289–1294

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Sex-related differences in maximal rate of isometric torque development

J. Greig Inglis, Rene Vandenboom, David A. Gabriel *

Electromyographic Kinesiology Laboratory, Faculty of Applied Health Sciences, Brock University, St. Catharine's, ON L2S 3A1, Canada

A R T I C L E I N F O

Article history:
Received 17 December 2012
Received in revised form 4 September 2013
Accepted 20 September 2013

Keywords:
Surface electromyography
Biceps brachii
Muscle strength
Elbow flexion

A B S T R A C T

Sex-differences in the maximum rate of torque development ($d\tau/dt_{max}$) may be due to differences in maximum muscle strength, because higher torque values mathematically lead to higher values for the rate of change in torque. The rate of change in the isometric torque-time curve is often normalized to the isometric maximum voluntary contraction (MVC) to evaluate males and females on a relative scale. Normalization eliminates sex-differences in $d\tau/dt_{max}$ in the lower limbs because males and females are more comparable (i.e., differences between the sexes are relatively small) with respect to both muscle size and strength. However, normalization fails to result in parody in $d\tau/dt_{max}$ of the upper limb, leading to the idea that other factors may be involved. This study determined if sex-differences in $d\tau/dt_{max}$ in the upper limb can be attributed to differences in isometric MVC and/or a neural variable related to rate of increase in muscle activation (Q_{30}). Forty-six participants (23 males, 23 females) performed maximal isometric elbow flexion contractions, "as hard and as fast as possible". Maximum torque (τ_{max}), $d\tau/dt_{max}$, and the rate of increase in surface electromyographic (sEMG) activity (Q_{30}) were assessed. Muscle plus bone cross-sectional area (M + B CSA) of the upper arm was calculated to estimate differences in muscle size, only for comparative purposes. Maximum strength (55.5%) and muscle size (41.9%) of the elbow flexors in males were much greater than that of females ($p < 0.05$). There was a large difference (61.2%) between males and females with respect to $d\tau/dt_{max}$ that was reduced by statistical correction using an analysis of covariance (ANCOVA). The percent differences were reduced to 36.7% ($p < 0.05$) for τ_{max} and 54.4% ($p < 0.05$) for Q_{30}, but was nearly eliminated to 13.8% ($p > 0.05$) when both variables were used simultaneously as covariates. Since sex-differences in the upper limb $d\tau/dt_{max}$ persist, additional neural or biomechanical factors may be involved.

1. Introduction

The rate of force development (RFD) is as important as maximal voluntary contraction (MVC) in characterizing skeletal muscle performance. Aside from the obvious implications for sport performance (Aagaard et al., 2002; Hannah et al., 2012), there is an appreciation for the RFD in activities of daily living (Shultz et al., 1997; Renner et al., 2009). A rapid increase in muscle force is critical for increasing joint stiffness in response to a sudden perturbation (Shultz and Perrin, 1999; Isabelle et al., 2003; Gruber and Gollhofer, 2004; Hopkins et al., 2009; Sefton et al., 2009), and to restore balance and prevent falls (Fukawaga and Schultz, 1995; Shultz et al., 1997). It has also been shown that the RFD in upper limb rehabilitation has a far greater relationship with functional capacity than MVC (Renner et al., 2009).

Hannah et al. (2012) recently demonstrated that sex-related differences in the maximum RFD are due to expected differences in MVC. When the maximum rate of torque development ($d\tau/dt_{max}$) during isometric knee extension was normalized with respect to MVC, sex-related differences were completely eliminated. It is possible that normalization was effective because males and females are generally more comparable (i.e., the percent differences are less) with respect to muscle mass and strength in lower versus upper limbs (Heyward et al., 1986; Miller et al., 1993; Hoffman et al., 1979). For example, Hannah et al. (2012) reported that males and females differed in maximal isometric knee extension strength by only 33%. Thus, we asked the question if the findings for the lower limb are generalizable to the upper limb where mass and strength differences between males and females are more pronounced (Heyward et al., 1986; Miller et al., 1993; Hoffman et al., 1979).

If sex-related differences in $d\tau/dt_{max}$ are due solely to MVC, then statistical control for MVC using an analysis of covariance or normalization by MVC should eliminate significant differences between males and females. However, it is possible that sex-related differences in $d\tau/dt_{max}$ for the upper limb may persist, because there is evidence for its neural regulation independent of MVC. For example, the superposition of normalized force–time curves

* Corresponding author. Address: Faculty of Applied Health Sciences, Brock University, 500 Glenridge Avenue St. Catharines, ON L2S 3A1, Canada. Tel.: +1 (905) 688 5550x4362; fax: +1 (905) 688 8364.

E-mail address: dgabriel@brocku.ca (D.A. Gabriel).

1050-6411/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jelekin.2013.09.005

pre- versus post-resistive exercise training typically exhibit a distinct shift to the left for the $d\tau/dt_{max}$ portion of the trace (Gabriel et al., 2001; Aagaard et al., 2002; Gruber and Gollhofer, 2004; Holtermann et al., 2007). Furthermore, previous work has shown that males and females can exhibit differences in the rate of increase in surface electromyographic activity (sEMG) during the maximal speed of limb movement (Ives et al., 1993). The underlying mechanism for differences in the rate of muscle activation may be that males have higher motor unit (MU) discharge rates during maximal isometric contractions (Christie and Kamen, 2010), and higher discharge rates are associated with a greater $d\tau/dt_{max}$ (Van Cutsem et al., 1998).

To this end, male and female participants in the present study performed maximal effort isometric contractions of the elbow flexors, to determine the contribution of MVC and rate of muscle activation to sex-related differences in $d\tau/dt_{max}$ in the upper limb. The two prevalent methods of data analysis of sex-related differences in muscle contractile characteristics are: (a) statistical control using an analysis of covariance, and (b) normalization by the creation of ratio scores prior to statistical analysis (Behm and Sale, 1994; Holmback et al., 2003; Hannah et al., 2012; Hoffman et al., 1979; Heyward et al., 1986). A secondary purpose was therefore to compare the two methods of data analysis and their impact on the interpretation of results.

2. Methods

2.1. Participants

Forty-six healthy subjects (23 females and 23 males) served as participants for the study. They were recruited from the Brock University undergraduate and graduate physical education programs and were right hand dominant. Participants had no prior orthopedic injuries of the upper limb or neurological disorders. Each subject provided informed consent prior to study participation in accordance with Brock University Research Ethics Board guidelines (REB-02-284).

2.2. Testing procedures

2.2.1. Participant characteristics

Participants reported to the Electromyographic Kinesiology Laboratory for two sessions. The first session was used to familiarize subjects with the demands of the task, obtain their physical characteristics, and complete a physical activity questionnaire (Table 1). The anthropometric data reported in Table 1 were used to calculate muscle (M) and bone (B) cross-section area (CSA) for the biceps according to the following formula:

Table 1
Characteristics of the study participants.

Measure	Females (N = 23) M ± SD	Males (N = 23) M ± SD
Age (years)	23 ± 1.6	23 ± 3.3
Height (m)	1.7 ± 0.1	1.8 ± 0.1*
Mass (kg)	63.3 ± 8.3	88.9 ± 12.3*
Forearm length (cm)	23.9 ± 1.5	29.1 ± 2.8*
Elbow circumference (cm)	23.5 ± 1.5	29.1 ± 2.8*
Biceps skin-fold (mm)	10 ± 3	8 ± 4*
Triceps skin-fold (mm)	20.5 ± 4.3	19.0 ± 10.2
Muscle-bone cross-sectional area (cm^2)	45.8 ± 8.0	78.8 ± 15. 7*
Physical activity (hours/week)	5.4 ± 5.4	4.8 ± 3.9
Weight training		
Years	4.3 ± 3.2	5.4 ± 3.8
Hours/Week	2.4 ± 2.1	4.4 ± 3.2*

* Significant at the $p < 0.05$ probability level.

$$M + B\ \text{CSA} = \pi \times (r - (\text{BSF} + \text{TSF})/4)^2$$

where r is the radius of the upper arm calculated from the biceps girth, BSF is biceps skinfold, and TSF is triceps skinfold (de Koning et al., 1986; Katch and Hortobagyi, 1990). Muscle-bone CSA obtained by anthropometric measures has been validated against the same measures calculated using both X-ray (Katch and Hortobagyi, 1990), CT (Cureton et al., 1988; Forbes et al., 1988; Rice et al., 1990), and MRI (Knapik et al., 1996). The anthropometric method is known to result in an overestimate in absolute terms but produce the same results when examining differences between males and females and alterations due to resistive exercise (Cureton et al., 1988; Knapik et al., 1996). Calculations for the corrected (bone free) arm muscle cross-sectional area proposed by Heymsfield et al. (1982) were not performed as Hortobágyi et al. (1990) demonstrated that the uncorrected formula was effective when studying the relationship between size and strength.

2.2.2. Strength measures

Data collection occurred during the second test session (Calder and Gabriel, 2007). Participants performed a total of seven isometric, maximal voluntary contractions (MVCs) of the elbow flexors. The contractions were held for five seconds and occurred at three minute intervals. The instructions were to flex at the elbow "as hard and as fast as possible", while verbal encouragement was given during each trial (McNair et al., 1996; Holtermann et al., 2007). Voltage from a load cell (JR3 Inc., Woodland, CA) was monitored using a digital display on a computer-based data acquisition system (DASYLab, DASYTEC National Instruments, Amherst, NH). At the same time, the voltage was presented to participants on an oscilloscope (Hitachi, VC-6525) situated at eye level. The visual gain of the oscilloscope (i.e., volts per division) was the same for every subject and remained constant through the study.

After the first contraction, a target line corresponding to the peak voltage was presented on the oscilloscope. Participants were instructed to move the voltage trace from the load cell, past the target line on the oscilloscope for the next two attempts. The target line was then adjusted to 110% of the peak voltage that occurred during any one of the first three trials. A fourth trial was then performed to determine if participants could reach the new target line. If participants could reach the new target line, then the new target line was 110% of the average of the peak voltages observed on trials 2, 3, and 4. This protocol has been shown to result in stable MVCs within four contractions and avoid fatigue (Baratta et al., 1998). Two additional horizontal lines were then used to construct a target area that was ±2.5% of the required force. After five minutes of rest, an additional three MVCs where obtained with the same work to rest ratio. The additional three contractions were required because intraclass reliability coefficients for maximal isometric elbow flexion contractions obtained on one test day begin to plateau (0.96–0.97) between contraction 5 and 7 (Carlson and Kroll, 1970).

2.3. Apparatus and testing position

The apparatus and test position have been described in detail elsewhere (Calder and Gabriel, 2007). Briefly, a seat-belt was used to secure participants at the waist to the testing chair. Shoulder straps crossing the midline of the torso further minimized any extraneous movement of the upper body. The upper arm rested at the back of the elbow on a support so the shoulder and elbow of the arm being tested were at 90° of flexion in the sagittal plane. A wrist cuff was fastened below the styloid process with Velcro straps while the forearm was in a neutral position (mid-way between pronation and supination). A load cell (JR3 Inc., Woodland, CA) attached to the wrist-cuff was used to record force.