Clinical Neurophysiology 128 (2017) 925–934

Contents lists available at ScienceDirect

Clinical Neurophysiology

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

Age-related differences in twitch properties and muscle activation of the first dorsal interosseous

Jonathan D. Miller, Trent J. Herda *, Michael A. Trevino, Adam J. Sterczala, Anthony B. Ciccone, Justin X. Nicoll

Neuromechanics Laboratory, Department of Health, Sport and Exercise Sciences, University of Kansas, Lawrence, KS 66044, USA

ARTICLE INFO

Article history:
Accepted 12 March 2017
Available online 24 March 2017

Keywords:
Contraction duration
Potentiation
Aging
Motor unit
Echo intensity
Ultrasound

HIGHLIGHTS

- Old individuals showed greater muscle activation with no changes in firing rates.
- Old individuals showed lower twitch force potentiation and longer twitch contraction duration.
- Altered muscle quality likely contributed to age-related changes in twitch contractile properties.

ABSTRACT

Objective: To examine twitch force potentiation and twitch contraction duration, as well as electromyographic amplitude (EMG_{RMS}) and motor unit mean firing rates (MFR) at targeted forces between young and old individuals in the first dorsal interosseous (FDI). Ultrasonography was used to assess muscle quality.

Methods: Twenty-two young (YG) (age = 22.6 ± 2.7 years) and 14 older (OD) (age = 62.1 ± 4.7 years) individuals completed conditioning contractions at 10% and 50% maximal voluntary contraction, (MVC) during which EMG_{RMS} and MFRs were assessed. Evoked twitches preceded and followed the conditioning contractions. Ultrasound images were taken to quantify muscle quality (cross-sectional area [CSA] and echo intensity [EI]).

Results: No differences were found between young and old for CSA, pre-conditioning contraction twitch force, or MFRs ($P > 0.05$). However, OD individuals exhibited greater EI and contraction duration ($P < 0.05$), and EMG_{RMS} (YG = 35.4 ± 8.7%, OD = 43.4 ± 13.2%; $P = 0.034$). Twitch force potentiation was lower for OD (0.311 ± 0.15 N) than YG (0.619 ± 0.26 N) from pre- to post-50% conditioning contraction ($P < 0.001$).

Conclusions: Lower levels of potentiation with elongated contraction durations likely contributed to greater muscle activation during the conditioning contractions in the OD rather than altered MFRs. Ultrasonography suggested age-related changes in muscle structure contributed to altered contractile properties in the OD.

Significance: Greater muscle activation requirements can have negative implications on fatigue resistance at low to moderate intensities in older individuals.

1. Introduction

Twitch force potentiation is a phenomenon in which the twitch force produced by motor units is increased temporarily as a result of recent activity (Hodgson et al., 2005). Classically, potentiation is quantified by changes in twitch force, via evoked non-voluntary stimuli, prior to and following a conditioning contraction, to quantify the potentiation that occurred during the contraction (Vandervoort and McComas, 1986; Hicks et al., 1991; Hamada

* Corresponding author at: Neuromechanics Laboratory, Dept. Health, Sport, and Exercise Sciences, University of Kansas, 1301 Sunnyside Ave, Room 101BE, Lawrence, KS 66045, USA. Fax: +1 785 864 3343.

E-mail addresses: j980m842@ku.edu (J.D. Miller), t.herda@ku.edu (T.J. Herda), adam.j.sterczala@ku.edu (M.A. Trevino), mtrevino@ku.edu (A.J. Sterczala), aciccone@ku.edu (A.B. Ciccone), justin.nicoll@ku.edu (J.X. Nicoll).

http://dx.doi.org/10.1016/j.clinph.2017.03.032
1388-2457/

et al., 2000). Twitch force increases following a conditioning contraction if muscle fibers were potentiated during the muscle action, particularly if higher-threshold motor units and/or fibers that primarily express fast-twitch characteristics were active (Vandervoort and McComas, 1986; Hamada et al., 2000; Fukutani et al., 2014). Potentiation is commonly attributed to phosphorylation of myosin regulatory light chains via a Ca^{2+} mediated mechanism/pathway (Sweeney et al., 1993; Hodgson et al., 2005; Zhi et al., 2005). The result of this pathway is an increase in the rate at which actin-myosin cross-bridges enter the force binding state (Sweeney and Stull, 1990). It has been reported as a secondary mechanism to maintain or increment force and is believed to decrease the rate of fatigue (Hicks et al., 1991; Sweeney et al., 1993; De Luca et al., 1996). Regulatory light chain phosphorylation can occur rapidly following the onset of excitation (~1–2 s), with dephosphorylation occurring relatively slowly over several minutes (Sweeney et al., 1993; Zhi et al., 2005). Prior to dephosphorylation, the muscle fiber is potentiated, providing the secondary force generation mechanism. In Theory, as force output is increased in potentiated fibers, fewer muscle fibers/motor units or lower firing rates are required to maintain the same absolute force and, therefore, decreasing neural activation of the motor unit pool.

Previous studies have reported altered motor unit firing rates, as a result of potentiation, following a conditioning contraction (Klein et al., 2001, 2002; Inglis et al., 2011) in young and old, such as, decreases in firing rates. In addition, other studies (Dorfman et al., 1990; De Luca et al., 1996; Adam and De Luca, 2005) have observed initial decreases in firing rates during steady force contractions, which in these instances served as conditioning contractions, while observing no additional motor unit recruitment or coactivation of the antagonist. The authors speculated there was a decrease in the demand for muscle activation because of the potentiation, as evidenced by the decrease in firing rates with no additional motor units recruited. In theory, reducing the neural drive or muscle activation, which reflects the number and/or firing rates of active motor units, would decrease energy expended during the initial task. Older individuals, with a reduced capacity for potentiation (Vandervoort and McComas, 1986), may need greater muscle activation to sustain a targeted force in comparison to younger individuals who express greater levels of potentiation. Indeed, Scaglioni et al. (2016) reported older individuals required greater levels of voluntary activation to reach similar submaximal forces during voluntary isometric contractions of the plantar flexors.

For older individuals, motor unit firing rates have been reported to be lower at targeted forces ranging from 20% to 50% in comparison to younger individuals (Erim et al., 1999; Dalton et al., 2009). A possible explanation for the lower firing rates in older individuals may be related to elongated twitch contraction durations, which could cause muscle fibers to tetanize at lower firing rates (Narici et al., 1991; Erim et al., 1999; Watanabe et al., 2016). In addition, Erim et al. (1999) and Watanabe et al. (2016) reported similar firing rates in lower- and higher-threshold motor units at targeted forces for older individuals, indicating that the onion skin control scheme may be less orderly due to age. It remains unclear the interplay of contraction duration and potentiation on motor unit recruitment and firing rate behavior. In theory, an age-related reduction in the ability to potentiate during a muscular action would require altered motor unit behavior (increased firing rates or recruitment) to reach and/or maintain a targeted force. Since it has been reported that older individuals exhibit lower firing rates at submaximal target forces, which may be due to increased contraction durations, it is possible that the greater activation requirement is satisfied by the recruitment of additional motor units as reported by Scaglioni et al. (2016). Furthermore, it is unknown if potentiation influences lower- and higher-threshold motor units in a similar manner. Investigation of the firing rates of lower- and higher-threshold motor units during conditioning contractions in older individuals is warranted, specifically the influence of potentiation and contraction duration (Narici et al., 1991; Connelly et al., 1999; Erim et al., 1999; Dalton et al., 2009; Watanabe et al., 2016).

Previous studies using ultrasonography to measure muscle size (cross-sectional area [CSA] or muscle thickness) and muscle quality (echo intensity [EI]) have reported age-related muscle atrophy and infiltration of non-contractile tissues within the muscle to reduce strength and performance (Morse et al., 2005; Cadore et al., 2012; Fukumoto et al., 2012; Wilhelm et al., 2014; Lopez et al., 2016). For example, lower muscle thickness and greater EI, indicating lower muscle quality, is associated with lower strength, power, and functional performance in aging men (Wilhelm et al., 2014). It is hypothesized that potentiation would be less and contraction duration would be elongated in healthy older individuals that possess higher EI and, subsequently, result in altered motor unit behavior.

The purpose of this study was to examine potential differences in muscle activation via electromyographic (EMG) amplitude and firing rates of lower- and higher-threshold motor units between young and older individuals during a conditioning contraction. In addition, twitch force potentiation and contraction duration were assessed to clarify the possible differences in muscle action and motor unit firing rates at the targeted forces. Finally, CSA and EI (muscle quality) were examined to determine if muscle atrophy is present in older individuals with impaired potentiation and elongated contraction durations. Twitch force potentiation, EMG amplitude, and motor unit firing rates were assessed at a low (10% of maximal voluntary contraction [MVC]) and moderate intensity contraction (50% MVC). It was expected that twitch force potentiation would be greater for the 50% than 10% MVC, (Vandervoort et al., 1983; Klein et al., 2001, 2002; Fukutani et al., 2014) and that the difference in twitch force potentiation between the contraction intensities may provide additional insight on the influence of potentiation on motor unit behavior. The first dorsal interosseous (FDI) muscle was chosen as it is the only muscle involved in the abduction of the index finger (Thomas et al., 1986) In addition, age-related disuse is less of a factor in a small hand muscle in comparison to a larger limb muscles (i.e., quadriceps), but yet the FDI is a mixed fiber type muscle similar to the vastus lateralis and rectus femoris muscles (Johnson et al., 1973).

2. Methods

2.1. Subjects

Twenty-two young (YG) individuals (12 men and 10 women, mean ± SD age = 22.6 ± 2.7 years, stature = 174.0 ± 7.8 cm; mass = 75.4 ± 16.2 kg) and 14 older (OD) individuals (7 men and 7 women, age = 62.1 ± 4.7 years, stature = 171.9 ± 8.7 cm; mass = 81.1 ± 15.3 kg) participated in this study. None of the participants reported any current neuromuscular diseases or musculoskeletal injuries specific to the hand or wrist. This study was approved by the University of Kansas Institutional Review Boards for Human Subjects. Prior to participation in the investigation, all participants completed a written informed consent form and a Pre-Exercise Testing Health & Exercise Status Questionnaire.

2.2. Research design

The participants visited the laboratory two times separated by at least 24 h. The first visit was a familiarization trial followed by