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Time-dependent neuromuscular parameters in the plantar flexors support greater fatigability of old compared with younger males

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ABSTRACT

Older adults are more fatigable than young during dynamic tasks, especially those that involve moderate to fast unconstrained velocity shortening contractions. Rate of torque development (RTD), rate of velocity development (RVD) and rate of neuromuscular activation are time-dependent neuromuscular parameters which have not been explored in relation to age-related differences in fatigability. The purpose was to determine whether these time-dependent measures affect the greater age-related fatigability in peak power during moderately fast and maximal effort shortening plantar flexions. Neuromuscular properties were recorded from 10 old (~78 years) and 10 young (~24 years) men during 50 maximal-effort unconstrained velocity shortening plantar flexions against a resistance equivalent to 20% maximal voluntary isometric contraction torque. At task termination, peak power, and angular velocity, and torque at peak power were decreased by 30, 18, and 16%, respectively, for the young ($p < 0.05$), and 46, 28, 30% for the old ($p < 0.05$) compared to pre-fatigue values with the old exhibiting greater reductions across all measures ($p < 0.05$). Voluntary RVD and RTD decreased, respectively, by 24 and 26% in the young and by 47 and 40% in the old at task termination, with greater decrements in the old ($p < 0.05$). Rate of neuromuscular activation of the soleus decreased over time for both age groups (~47%; $p < 0.05$), but for the medial gastrocnemius (MG) only the old experienced significant decrements (46%) by task termination. All parameters were correlated strongly with the fatigue-related reduction in peak power ($r = 0.81–0.94$, $p < 0.05$), except for MG and soleus rates of neuromuscular activation ($r = 0.25–0.30$, $p > 0.10$). Fatigue-related declines in voluntary RTD and RVD were both moderately correlated with MG rate of neuromuscular activation ($r = 0.51–0.52$, $p < 0.05$), but exhibited a trend with soleus ($r = 0.39–0.41$, $p = 0.07–0.09$). Thus, time-dependent factors, RVD and RTD, are likely important indicators of intrinsic muscle properties leading to the greater age-related decline in peak power when performing a repetitive dynamic fatigue task, which may be due to greater fatigue-related central impairments for the older men than young.

1. Introduction

Age-related alterations within the neuromuscular system contribute to declines in muscle strength, contractile speed and power, leading to greater age-related fatigability during dynamic tasks (Dalton et al., 2015, 2012, 2010; McNeil and Rice, 2007; Power et al., 2012) and ultimately reduced functional capacity (Clark et al., 2011; Power et al., 2013). During sustained isometric tasks older adults are often less fatigable than younger adults (Christie et al., 2011) until more advanced ages (Justice et al., 2014), but during constrained velocity (e.g., isokinetic) dynamic tasks older adults exhibit less (Lanza et al., 2004; Rawson, 2010), the same (Callahan et al., 2009; Dalton et al., 2012; Yoon et al., 2013) or more fatigue (Baudry et al., 2007; Callahan and Kent-Braun, 2011). With adult aging there may be a greater dependence on oxidative pathways for energy production (Lanza et al., 2005), perhaps helping to mitigate fatigue during isometric tasks (Tevald et al., 2010), but muscle economy is less in older adults during isotonic-like contractions (Layec et al., 2014). Therefore, during moderately fast unconstrained shortening contractions (isotonic-like) older adults are unequivocally more fatigable than young (Dalton et al., 2015, 2012, 2010; McNeil and Rice, 2007; Petrella et al., 2005); yet, the age-related neuromuscular factors contributing to the greater fatigability of older adults have yet to be elucidated.

Contractile velocity during voluntary efforts has emerged as a key contributor to the age-related decrements in power and daily function, including fatigability (Bean et al., 2011; Callahan and Kent-Braun, 2011; Dalton et al., 2010; Pojednic et al., 2012), but the underlying determinants are not well understood. Time-dependent performance measures

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(i.e., rate of neuromuscular activation, rate of torque development (RTD) and acceleration (rate of velocity development - RVD)) may be key parameters that fundamentally determine velocity of shortening and torque and hence peak power (Andersen and Aagaard, 2006; Clark et al., 2011; Thompson et al., 2014a, 2014b) in the context of fatigue. In humans, RTD at the initiation of contraction is associated with muscle fiber composition type (Harridge et al., 1996), whole muscle cross sectional area (Aagaard and Thorstensson, 2003), and viscoelastic properties of the muscle-tendon complex (Bojsen-Møller et al., 2005). Contractile properties related to RTD have been explored thoroughly as primary factors involved in the achievement of maximal isometric torque (Andersen and Aagaard, 2006), and both voluntary (Thompson et al., 2014b) and involuntary (Dalton et al., 2009) RTD have been reported to be less in old compared with young. Conversely, in aged animals at the motor unit (Łochynski et al., 2010) and whole muscle levels (Ballak et al., 2014) rate of force development does not seem to be altered with aging despite a slowing of relaxation time, thus voluntary control (i.e., rate of activation) may be a limiting factor in RTD. However, less is known regarding dynamic contractile performance, even though neuromuscular factors underlying RTD are likely critical in overcoming an isotonic load during shortening contractions. Further, dynamic movements involve shorter time durations to generate peak torque and power than maximal voluntary isometric contractions (MVCs) (Thorstensson et al., 1976), therefore time-dependent measures may characterize important physiological or biomechanical factors that limit the generation of peak power during fatiguing unconstrained velocity shortening contractions.

Once the isotonic load is overcome during an unconstrained shortening contraction and the isometric phase is complete, a rapid acceleration is required to achieve peak power. In turn, acceleration (RVD) can be limited by rate and cycling time of cross-bridge attachments, which is slowed in both animals (Ballak et al., 2014, Łochynski et al., 2010) and humans (Power et al., in press; Miller et al., 2014) with adult aging. Further, RVD is reduced to a greater extent than peak velocity alone in older adults compared with young (Thompson et al., 2014a, 2014b) and may be a better indicator of neuromuscular performance than instantaneous velocity because the time required to reach maximum velocity may be more relevant than the maximum velocity per se. Peak power is the maximum instantaneous value of the torque-velocity relationship, but it is not simply the product of peak torque and peak velocity. Because peak velocity often occurs later than peak power (Dalton et al., 2015) during shortening contractions, peak velocity may not reflect fully the contractile characteristics needed to generate power quickly. Rather, RVD (i.e., acceleration) may be necessary to achieve optimal velocity for a given load throughout a fixed range of motion. However, little is known regarding RVD and its implications on muscle fatigue during dynamic contractions.

These time-dependent parameters are not only representative of contractile properties, but also the ability of an individual to voluntarily activate the muscle quickly (Aagaard et al., 2002; Thompson et al., 2014b). Thus, to elucidate whether time-dependent measures generated by voluntary effort reveal age-related limitations at the central or peripheral level, we measured both voluntary RTD during the unconstrained velocity shortening task (RTD_{VOL}) and involuntary RTD for the electrically evoked twitch (RTD_{TW}) responses at pre-fatigue and post-task termination. In addition, we measured rates of neuromuscular activation because this factor is positively related to muscle power and function (Clark et al., 2011; Reid et al., 2012), but it is unknown whether it is a key factor in the greater fatigability of older adults than young during dynamic shortening contractions.

The purpose of this study was to determine whether time-dependent neuromuscular factors (i.e., RTD, RVD, and rate of neuromuscular activation) support the increased reduction in power in older males compared with younger counterparts during an unconstrained velocity shortening plantar flexor task. We hypothesized that pre-fatigue values for RTD (both involuntary and voluntary), RVD, and rate of neuromuscular activation would be lower in the older men than young. We expected RTD, RVD, and rate of neuromuscular activation would be reduced to a greater extent with fatigue in the older adults, and that fatigue-related changes in these time-dependent measures would be strongly and positively correlated with changes in peak power.

2. Methods

2.1. Participants

Twenty healthy, recreationally active men with no reported history of neuromuscular disease volunteered for this study. The ten older participants (age 77.5 ± 3.0 years, height 175.5 ± 7.9 cm, body mass 88.6 ± 13.1 kg) were recruited from a local exercise group; whereas the ten young (age 24.1 ± 2.8 years, height 175.0 ± 8.7 cm, body mass 78.6 ± 7.9 kg) were recruited from the local university population. None of the participants were engaged in systematic training but did participate in moderate levels of recreational activity 3–5 days per week. The data reported here were extracted from an unprocessed dataset from an earlier study (Dalton et al., 2010), but with novel analyses of variables related to the current purpose. Prior to testing, each participant granted oral and written informed consent. All procedures conformed to the Declaration of Helsinki and were approved by the local University's ethics review board for human research.

2.2. Experimental arrangement

During a single testing session, all procedures were conducted on a Biodex System 3 multi-joint dynamometer (Biodex Medical Systems, Shirley, New York, United States) using either the isometric or isotonic mode. The hip and knee angle were maintained at 90° while the participants were seated and reclined comfortably. Ankle angle was positioned to 10° of dorsiflexion during the isometric contractions and for the starting point of the unconstrained velocity shortening contractions. The foot of the dominant leg (right) was secured to the footplate with two Velcro inelastic straps across the toes and the dorsum of the foot while a custom binding secured the ankle. The torso of the participant was secured to the Biodex by inelastic straps fastened across the shoulders and waist. To minimize extraneous leg movement, the thigh was supported and stabilized with an inelastic strap. The lateral malleolus was aligned with the dynamometer's axis of rotation. Plantar flexor torques, velocities, and positions were sampled with a 12-bit analog-to-digital data acquisition board (Power 1401; Cambridge Electronic Design, Cambridge, UK) at 100 Hz and stored on a personal computer using Spike2 software (Cambridge Electronic Design, Cambridge, UK).

Prior to surface electromyography (EMG) electrode placement, the skin sites were cleaned with isopropyl alcohol swabs. Next, one pair of self-adhering surface pediatric cloth electrodes (H59P Repositionable Monitoring Electrodes; Kendall, Mansfield, MA) was placed over the muscle belly of the medial gastrocnemius (MG) and another ~2 cm below the lateral gastrocnemius border over the soleus using a 2-cm inter-electrode distance (center-to-center), respectively. A ground electrode was fixed over the right patella. Surface EMG signals were pre-amplified (×100; NL844, Digitimer Limited, Welwyn Garden City, England), amplified (×2; NL820A, Digitimer Limited, Welwyn Garden City, England), bandpass filtered (10–1000 Hz; NL136, Digitimer Limited, Welwyn Garden City, England), converted digitally and sampled at 2000 Hz (Power 1401, Cambridge Electronic Design, Cambridge, UK).

A bar-type stimulating electrode was held firmly in the distal portion of the popliteal fossa to evoke plantar flexion twitches via the tibial nerve. A single stimulus was delivered via a square-wave pulse with a duration of 100 μs at 400 V (DS7AH; Digitimer Limited, Welwyn Garden City, UK).