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The age-related slowing of voluntary shortening velocity exacerbates power loss during repeated fast knee extensions

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ABSTRACT

Older adults are less fatigable than young during isometric tasks, but this apparent ability to resist fatigue is often abolished when dynamic actions are performed. These findings could indicate that the velocity component of dynamic contractions or the task performed is an important factor in explaining fatigability of older adults. However, it has not been evaluated systematically. The purpose was to investigate the differences in age-related fatigue of the knee extensors in 8 older (73.6 ± 3.5 years) and 8 younger (25.1 ± 2.6 years) men. Neuromuscular measures were collected at baseline, during and immediately following task termination of three different maximal effort knee extension tasks. On three separate days, participants performed either 30 slow (1.05 $rad \cdot s^{-1}$, 60° $\cdot s^{-1}$) or 30 moderate (3.14 $rad \cdot s^{-1}$, 180° $\cdot s^{-1}$) isovelocity contractions, or 30 fast unconstrained velocity contractions with a fixed resistance (i.e., 20% maximal voluntary isometric contraction). At baseline, the older men were 25% and 35% less powerful than the younger men for the slow and moderate isovelocity tasks, respectively, but 42% less for the fast unconstrained velocity protocol. At task termination for the slow (old: 53%, young: 53%) and moderate (old: 45%, young: 38%) isovelocity fatigue tasks, power was reduced similarly in both age groups. However, for the fast unconstrained velocity task, power was reduced by a greater extent in older (35%) than the younger men (23%) at task termination. These results highlight that age-related impairments in voluntary shortening velocity exacerbate reductions in power production during repetitive dynamic tasks. Furthermore, the importance of this factor is masked when velocity is constrained (isovelocity) and fatigue is dependent primarily upon slow torque generation.

1. Introduction

Adult aging is accompanied by various alterations in the neuromuscular system that lead to reductions in strength and power, and ultimately muscle function (Aagaard et al., 2010). Age-related architectural (Narici and Maganaris, 2007) and functional (Hunter et al., 1999) changes contribute to a slowing in whole muscle contractile properties resulting in a leftward shift in the torque–frequency relationship (Roos et al., 1999). Slowed isometric contractile properties may allow for more economical muscle activation through reduced motor unit discharge rates (Dalton et al., 2010a) and therefore lower ATP turnover (Kent-Braun, 2009) in older adults. Thus, during relative isometric fatiguing tasks older adults are less fatigable than younger adults (Kent-Braun, 2009).

When contractile velocity is included with measures of strength (torque), power (i.e. torque × velocity) can be calculated to assess muscle capacity during a dynamic fatiguing task. For dynamic contractions, conflicting reports suggest that older adults are more fatigable (Dalton et al., 2010b; Petrella et al., 2005), less fatigable (Lanza et al., 2004; Rawson, 2010), or even similar (Callahan et al., 2009; Laforest et al., 1990) when compared with younger adults. Furthermore, the relatively few studies on fatigue and aging have focused more on the force or torque (i.e., isovelocity tasks) component of power, rather than velocity. During these tasks, velocity is constrained (i.e., pre-set) and changes in power are related directly to alterations in torque production, despite shortening velocity being a key component strongly related to the inherent design properties of skeletal muscle (Lieber and Ward, 2011).

For most all studies on age-related fatigue during dynamic tasks, the knee extensors have been utilized (Petrella et al., 2005; Rawson, 2010; Callahan et al., 2009; Laforest et al., 1990; Aniansson et al., 1978; Deschenes et al., 2008; Larsson and Karlsson, 1978; Lindstrom et al., 2006, 1997), but those studies were limited to slow and moderate knee extension tasks (1.57–4 $rad \cdot s^{-1}$). Indeed, during

Abbreviations: ANOVA, Analysis of Variance; ATP, Adenosine triphosphate; EMG, Electromyography; ES, Effect size; HRT, Half relaxation time; M-wave, Compound muscle action potential; MVC, Maximal voluntary isometric contraction; ROM, Range of motion; TPT, Time to peak twitch torque.

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natural gait, knee angular velocities can reach $\geq 6.7\ \text{rad}\cdot\text{s}^{-1}$ in older and younger adults (Jevsevar et al., 1993). However, these faster velocities have not been tested using the isovelocity paradigm. This is because older adults are not capable of producing a reliable torque output throughout a full range of motion (ROM) at knee extension velocities greater than $4.71\ \text{rad}\cdot\text{s}^{-1}$ (Lanza et al., 2003) during constrained isovelocity tasks.

It is clear from these studies that an important variable not properly or thoroughly explored is the effect of voluntarily controlled shortening velocity on age-related fatigability. Utilizing a fatigue task with a relative fixed resistance (i.e., % MVC) and subject-dependent unconstrained shortening velocity should provide a more meaningful and practical assessment of power loss during a dynamic fatigue task, especially when the task is performed at moderate to high joint angular velocities. One challenge in assessing power loss during fatigue is to understand the relative contribution from each factor (i.e., torque and velocity) without the confounding effects of ROM failure, which is an important variable to consider when assessing dynamic muscle performance (Cheng and Rice, 2010). Therefore, an alternate and complementary paradigm is required to overcome these limitations and to evaluate fully the influence and importance of velocity during dynamic tasks in older adults.

Furthermore, a major limitation of extracting meaningful results from previous studies investigating age-related fatigue during dynamic tasks include: differences in the ages of participants, muscle groups tested, and experimental protocols. Because of the task-dependent nature of fatigue (Hunter, 2009) and the inconsistencies among protocols it is difficult to draw conclusions based upon the equivocal results presented in the literature. Importantly, no study has compared in the same subjects different velocity paradigms to fully evaluate the importance of shortening velocity on age-related fatigue

To resolve some of the above discrepancies between testing modalities and to better understand the effect of voluntary shortening velocity on power loss during fatigue, we designed a study in which the same participants performed three different dynamic fatiguing protocols at different contractile velocities. To alter velocity using a constant resistance that could be moved through a complete ROM for several contractions we used a combination of isovelocity and unconstrained velocity paradigms (further explained in Materials and methods). Due to inherent age-related contractile slowing (Roos et al., 1999; Dalton et al., 2010b), this model is helpful to test the influence of velocity on power loss during dynamic fatiguing contractions in comparison with younger adults possessing faster contractile function. We expected that the older men would exhibit less fatigue (less power loss) than the younger men during a slow ($1.05\ \text{rad}\cdot\text{s}^{-1}$) isovelocity task because these dynamic contractions would be less affected by factors that impair velocity and thus similar to an isometric task (0 velocity). During a moderate isovelocity task ($3.14\ \text{rad}\cdot\text{s}^{-1}$) we hypothesized fatigue would be similar between age groups because velocity impairments would have an increased influence and thus compete with those factors that provided an advantage to older men when the task is isometric or slow. However, during the fast unconstrained velocity actions ($>4\ \text{rad}\cdot\text{s}^{-1}$) the older men would exhibit greater fatigue than their younger counterparts because impairments in muscle contractile speed and shortening velocity would be the main factors responsible for the loss of power.

2. Materials and methods

2.1. Participants

Eight older men (age: 73.6 ± 3.5 years, height: 175.8 ± 4.4 cm, body mass: 85.0 ± 9.6 kg) and eight younger men (age: 25.1 ± 2.6 years, height: 175.4 ± 8.2 cm, body mass: 77.8 ± 13.1 kg) volunteered for this study and completed all fatigue protocols. To eliminate sex-related differences as a covariate of the muscle fatigue response (Hunter, 2009) this study included only men. The older participants were recruited from a local activity group designed to maintain flexibility, muscle endurance and cardiovascular fitness through regularly scheduled exercise classes three times per week. The younger men, recruited from the university population, were not systematically trained and participated in moderate exercise approximately three times per week. All participants reported they were healthy and recreationally active with no evidence of neuromuscular disease. Oral and written informed consent was obtained from each participant prior to experimental testing. The local university's ethics review board for experimentation on humans approved the study and all procedures conformed to the Declaration of Helsinki.

2.2. Experimental arrangement

A Biodex System 3 multi-joint dynamometer (Biodex Medical Systems, Shirley, NY) was used to record knee extensor torque, knee position and velocity in the isometric, isokinetic and isotonic modes with all tests performed on the right (dominant) leg. Participants were seated comfortably in an upright position with the hip angle at ~100° (~1.74 rad). The knee angle was set at 90° (1.57 rad) for all isometric measures. Range of motion for all dynamic contractions was set at 90°. The initial position for all dynamic knee extensions was set at 90° from terminal knee extension. To minimize extraneous body movements, the participants were fastened securely to the chair with inelastic straps around the shoulders, hips and right thigh. The knee joint was aligned with the axis of rotation of the dynamometer and an inelastic strap, ~2 cm superior to the malleoli, secured the leg to the dynamometer knee attachment. All knee extensor torques, velocities and positions were sampled at 100 Hz using a 12-bit analog-to-digital converter (Power 1401; Cambridge Electronic Design, Cambridge, UK) and digitized online using Spike2 software (Cambridge Electronic Design).

To assess isometric contractile properties, voluntary activation and sarcolemma excitability, electrically evoked twitches and compound muscle action potentials (M-waves) were elicited from the knee extensors using two custom-made aluminum electrode pads at a knee angle of 90° (1.57 rad). These electrodes were wrapped in thin conductive gel-soaked paper towel and applied transversely to the thigh with cloth tape. One electrode was positioned ~7 cm distal to the greater trochanter of the femur and the other was positioned ~6 cm distal to the inferior edge of the proximal stimulating electrode. Depending on the size of the thigh and to ensure the greatest muscle mass activation of knee extensors without activation of antagonist muscles, the stimulating electrode pad sizes varied accordingly ($8–11 \times 16–20$ cm). Visual inspection and palpation was used to ensure only the knee extensors were activated by the electrical stimulation. Single stimuli were generated via a 100-μs square wave pulse set at a maximal voltage of 400 V (Digitimer stimulator, model DS7AH; Digitimer Ltd., Welwyn Garden City, UK).

Surface electromyography (EMG) signals were recorded from the vastus medialis using self-adhering surface pediatric cloth electrodes (H59P Repositionable Monitoring Electrodes; Kendall, Mansfield, Massachusetts). To minimize a stimulation artifact in the M-wave response and to ensure proper stimulation pad placement, EMG signals were recorded only from the vastus medialis. Prior to electrode placement, the skin was cleaned with alcohol. Using a 3 cm inter-electrode distance, an electrode pair was positioned over the vastus medialis muscle belly in parallel with the muscle fibers and a ground electrode was positioned over the right patella. Surface EMG signals were preamplified (×100), amplified (×2), bandwidth filtered (10 Hz to 1 kHz), converted by a 12-bit analog-to-digital converter (Power 1401, Cambridge Electronic Design), and sampled on-line at 2000 Hz.

2.3. Experimental procedures

Data were collected over three visits to the neuromuscular laboratory, in which a randomly selected dynamic knee extension fatigue