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Fatigability of the dorsiflexors and associations among multiple domains of motor function in young and old adults

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ABSTRACT

Declines in neuromuscular function, including measures of mobility, muscle strength, steadiness, and patterns of muscle activation, accompany advancing age and are often associated with reduced quality of life and mortality. Paradoxically, older adults are less fatigable than young adults in some tasks. The purpose of this study was to determine the influence of age on fatigability of the dorsiflexors and to evaluate the ecological validity of this test by comparing it to motor function subdomains known to decline with advancing age. The community-dwelling older adults (n = 52, 75.2 ± 6.0 years) were more fatigable than young adults (n = 26, 22.2 ± 3.7 years), as assessed by endurance time for supporting a submaximal load (20% of one-repetition maximum; 1-RM) with an isometric contraction of the dorsiflexor muscles (8.9 ± 0.6 min and 15.5 ± 0.9 min, $p < 0.001$), including participants matched for 1-RM load and sex (Y: 13.3 ± 4.0 min, O: 8.5 ± 6.1 min, n = 11 pairs, 6 women, $p < 0.05$). When the older adults were separated into two groups (65–75 and 76–90 years), however, only endurance time for the oldest group was less than that for the other two groups ($p < 0.01$). All measures of motor function were significantly correlated (all $p < 0.05$) with dorsiflexor endurance time for the older adults, and multiple regression analysis revealed that the variance in endurance time was most closely associated with age, steadiness, and knee flexor strength ($R^2 = 0.50$, $p < 0.001$). These findings indicate that dorsiflexor fatigability provides a valid biomarker of motor function in older adults.

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1. Introduction

Age-associated declines in motor function—the ability to perform physical tasks (Reuben et al., 2013)—are tightly coupled with quality of life (Cooper et al., 2011; Manini et al., 2007), independent-living status (Bischoff et al., 2003), disability (Guralnik et al., 1995; Rantanen et al., 1999), and mortality (Buchman et al., 2007; Rantanen et al., 2012; Stanaway et al., 2011). Such associations are expected given that muscle strength (Forrest et al., 2007; Vandervoort, 2002), walking endurance (Rikli and Jones, 1999), sit-to-stand times (Bohannon, 2006), and fine motor skills (Enoka et al., 2003; Marmon et al., 2011) all decline with advancing age. In contrast, fatigability (Kluger et al., 2013), the rate of decline in objective measures of motor performance, can be less (Ditor and Hicks, 2000; Griffith et al., 2010; Hunter et al., 2005; Kent-Braun et al., 2002; Lanza et al., 2004) or greater (McNeil and Rice, 2007) in older adults than in young adults.

Differences in fatigability between young and older adults are attributable to several factors (Christie et al., 2011; Enoka, 2012). For example, average power produced by the dorsiflexor muscles during 25 dynamic contractions performed at maximal velocity declined more rapidly for the oldest men relative to young men (McNeil and Rice, 2007). In contrast, endurance time for a sustained submaximal isometric contraction with the dorsiflexor muscles was greater for older adults (men and women) than for strength-matched young adults (Griffith et al., 2010); and meta-analysis suggested that the type of fatiguing contraction used to compare performance (isometric versus dynamic) might underlie these divergent results. However, the age of the older participants also appears to influence the outcome of such comparisons, although there are too few studies that have included older adults in multiple decades of life for this association to be assessed quantitatively (Christie et al., 2011). Nonetheless, one study did find that the fatigability exhibited by men aged 60–69 years did not differ from that for younger (22–33 years) and older (80–90 years) men, whereas there was a significant difference between the young and oldest men (McNeil and Rice, 2007). The primary aim of the current investigation was to determine the association between age and fatigability of the dorsiflexor muscles in young and older adults (65–90 years), including a subset of strength-matched young and older adults, when supporting

Abbreviations: MVC, maximal voluntary contraction; 1-RM, one-repetition maximum; EMG, electromyography; aEMG, average electromyography amplitude; SD, standard deviation; CV, coefficient of variation; RPE, rating of perceived exertion; R^2, coefficient of determination.

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a submaximal inertial load for as long as possible. Based on the report of McNeil and Rice (2007), we hypothesized that endurance time would be briefest in the oldest adults when the task required supporting a submaximal load for as long as possible.

To assess the ecological validity of the fatigability test, a secondary aim of the current study was to examine the association between dorsiflexor endurance time and other measures of motor function that typically decline with advancing age. The comparisons included measures of mobility, muscle strength, steadiness, and patterns of muscle activation (Justice et al., 2014a). Because maintaining the position of a limb is a fundamental element of many activities of daily living, we hypothesized that endurance time for the fatiguing contraction would be significantly associated with other measures of motor function, especially in older adults. The unique features of the study included a relatively large sample of older adults covering a broad range of ages (65–90 years), a subset of strength-matched young and older adults, the assessment of fatigability with a functionally relevant task, and comparison of the fatigability measurement with clinically relevant tasks used to characterize age-related declines in motor function.

2. Materials and methods

2.1. Human subjects

Fliers and local advertisements were used to recruit 52 older (65–90 years) and 26 young (19–30 years) participants from Boulder, Colorado. Subjects were free of neurological disorders, chronic pain, diabetes, advanced chronic disease states, and any other condition that might limit safe participation. Prior to the tests of motor function, physicians at the Clinical Translational Research Center (CTRC) located at the University of Colorado Boulder obtained medical histories and performed physical examinations for all older participants to ensure subject safety and ability to perform the rigorous physical tests. Older participants were also administered a modified activity questionnaire during this screening session. Young subjects were screened for physical activity status (light and moderate activity levels included) for comparison with the estimated activity levels for older adults. All procedures were approved by the Institutional Review Board and conducted in accordance with the Declaration of Helsinki.

2.2. Motor function testing overview

Motor function was assessed with measures of mobility, muscle strength, steadiness, and fatigability during a single, ~3-hour session in the Neurophysiology of Human Movement Laboratory of the University of Colorado Boulder campus. Table 1 provides an overview of the motor function testing session and outcomes. Subjects, especially those aged 80–90 years, were allowed ample rest time between physical tests to ensure safety and adequate recovery from the previous task; the breaks times listed in Table 1 reflect minimal rest times after each test. The experimental apparatus used to measure strength, steadiness, and fatigability are shown in Fig. 1.

2.3. Electrical and mechanical recordings

The force exerted by the limb during the strength, steadiness, and fatigability tasks was measured with a strain-gauge transducer (MLP-300, Transducer Techniques, Ternecula, CA) (Fig. 1). The force signal was low-pass filtered (0–50 Hz; Coulbourn Instruments, Allentown, PA), recorded on a computer, and digitized at 1000 samples/s. In addition, muscle activity (EMG) was recorded with surface electrodes (Ag–AgCl, 8-mm diameter, 20-mm distance between electrodes) placed over the tibialis anterior, medial gastrocnemius, rectus femoris, and vastus lateralis, as described previously (Rudroff et al., 2010). The EMG signals were amplified (× 2000), band-pass filtered 12–1000 Hz; (Coulbourn Instruments, Allentown, PA), recorded on a computer, and digitized at 2000 samples/s. Absolute and relative fluctuations in force and EMG were quantified in 10-s epochs at absolute and relative time points during steadiness and fatigability tasks via a custom MATLAB program (version 7.2, R2006a, MathWorks, Natick, MA). Coactivation of agonist and antagonist muscles was calculated during the steadiness and fatigability tasks as an assay of the neural control strategy used to maintain limb position during isometric contractions (Baudry et al., 2010). Coactivation was quantified as the ratio of EMG amplitude for medial gastrocnemius relative to the average amplitude for tibialis anterior and medial gastrocnemius during the dorsiflexor contractions (Falconer and Winter, 1985).

2.4. Mobility

Mobility was quantified with measures of endurance walk and sit-to-stand times. Mobility has been identified by the International

Table 1
Overview of motor function tests.

Subdomain	Test	Equipment	Trials	Breaks	Variables	Outcome
Mobility						
	500 m walk	Indoor track	1	10	Time	Endurance walk time
	Five sit-to-stand	Standard height chair	1	15	Time	Sit-to-stand time
Strength						
	Dorsiflexor 1-RM	Weights	6–8	5	Mass lifted (kg)	1-RM for load determination
	Knee extensor MVC	Force transducer	3–5	5	Torque per mass	Knee extensor strength
	Knee flexor MVC	Force transducer	3–5	5	Torque per mass	Knee flexor strength
	Dorsiflexor MVC	Force transducer	3–5	5	Torque per mass	Dorsiflexor strength
	–	–	–	–	Average torque per mass	Composite lower body strength
Steadiness						
	60 s dorsiflexor isometric	Force transducer	1	10	SD and CV for force	Steadiness @5% 1-RM
	contraction @5% 1-RM	EMG	–	–	EMG amplitude (TA and MG)	Coactivation ratio
	60 s dorsiflexor isometric	Force transducer	1	20	SD and CV for force	Steadiness @20% 1-RM
	contraction @20% 1-RM	EMG	–	–	EMG amplitude (TA and MG)	Coactivation ratio
Fatigability						
	Dorsiflexor isometric contraction for	Weights	1	–	Time	Endurance time
	as long as possible @20% 1-RM	EMG	–	–	EMG amplitude (TA, MG, KE)	EMG amplitude (% initial)
		Force transducer	–	–	SD and CV for force	SD and CV for force
		0–10 scale	–	–	RPE	RPE

Tests are listed in order of presentation. Rest intervals between strength trials were 60 s. Breaks are reported as minimal rest times after each test (min). 1-RM, one-repetition maximum; CV, coefficient of variation; EMG, electromyogram; KE, knee extensors; MVC, maximal voluntary contraction; MG, medial gastrocnemius; RPE, rating of perceived exertion; SD, standard deviation; TA, tibialis anterior.

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