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Does quadriceps neuromuscular activation capability explain walking speed in older men and women?

David J. Clark [a,b,c,*], Kieran F. Reid [a], Carolynn Patten [b,d], Edward M. Phillips [a,e], Sarah A. Ring [b], Samuel S. Wu [f], Roger A. Fielding [a]

[a] Nutrition, Exercise Physiology and Sarcopenia Laboratory, Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston, MA, USA
[b] Brain Rehabilitation Research Center, Malcom Randall VA Medical Center, Gainesville, FL, USA
[c] Department of Aging and Geriatric Research, University of Florida, Gainesville, FL, USA
[d] Department of Physical Therapy, University of Florida, Gainesville, FL, USA
[e] Department of Physical Medicine and Rehabilitation, Harvard Medical School and Spaulding Rehabilitation Hospital, Boston, MA, USA
[f] Department of Biostatistics, University of Florida, Gainesville, FL, USA

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ABSTRACT

Age-related impairment of neuromuscular activation has been shown to contribute to weakness in older adults. However, it is unclear to what extent impaired neuromuscular activation independently accounts for decline of mobility function. The hypothesis of this study is that the capability to produce rapid neuromuscular activation during maximal effort leg muscle contractions will be shown to be an independent predictor of mobility function in older men and women after accounting for muscle size and adiposity, body composition and age. Twenty six older men and eighteen older women (aged 70–85 years) participated in this study. Mobility function was assessed by the 400-m walk test. Neuromuscular activation of the quadriceps muscle group was assessed by surface electromyography ("rate of EMG rise"). Thigh muscle cross sectional area and adiposity were assessed by computed tomography. In males, univariate regression analysis revealed strong associations between walking speed and a number of predictors including age ($p < 0.01$), muscle area ($p < 0.01$), intermuscular adipose tissue area ($p < 0.01$), and rate of EMG rise ($p < 0.001$). Subsequent multiple regression analysis with all variables accounted for 72% of the variability in walking speed ($p < .0001$), with age and rate of EMG rise as the dominant variables in the model. In females, univariate analysis showed a significant association only between walking speed and subcutaneous adipose tissue area ($p < 0.05$). Multiple regression analysis accounted for only 44% of the variability in walking speed, and was not statistically significant ($p = 0.18$). The present findings indicate that the capability to rapidly activate the quadriceps muscle group is an important factor accounting for inter-individual variability of walking speed among older men, but not among older women. This research is important for informing the design of assessments and interventions that seek to detect and prevent impairments that contribute to age-related mobility disability.

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1. Introduction

Mobility deficits threaten the independence of older adults by contributing to falls, fractures, depression, hospital admissions and restricted life role activities. Research is needed to better understand the underlying causal impairments contributing to mobility deficits so that clinical assessments and interventions can be appropriately designed to focus on those impairments. Considerable evidence now indicates that weakness, and specifically loss of power production capability, is an important determinant of the onset and progression of mobility deficits (Bean et al., 2002; Cuoco et al., 2004; Foldvari et al., 2000). Loss of power production has a multi-factorial etiology, and our recent studies indicate that impaired neuromuscular activation is an important factor (Clark & Fielding, 2012; Reid et al., 2012). However, the extent to which neuromuscular activation capability accounts for mobility function in older men and women remains unclear.

Preliminary work suggests the presence of a link between neuromuscular activation and mobility function in older adults. Rapid neuromuscular activation of the quadriceps muscle group measured during a chair stand appears to contribute to faster walking speed (Brach et al., 2001). Similarly, rapid neuromuscular activation during maximal effort contractions in the quadriceps and plantarflexor groups is positively associated with walking speed and Short Physical Performance Battery score (Clark et al., 2011; Clark et al., 2013). Furthermore, improvements in lower extremity neuromuscular activation induced by resistance

* Corresponding author at: Brain Rehabilitation Research Center (151A), Malcom Randall VA Medical Center, 1601 SW Archer Rd, Gainesville, FL 32608, USA. Tel.: +1 352 376 1611x5244; fax: +1 352 379 2332.
E-mail address: davidclark@ufl.edu (D.J. Clark).

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training have been linked to increased speed of stair ascent in older adults (Holsgaard-Larsen et al., 2011). These prior findings demonstrate the need to more fully investigate the effect of neuromuscular activation on mobility function relative to other physical factors of known functional significance. Accordingly, the objective of this study was to determine if the capability to produce rapid neuromuscular activation is an independent determinant of mobility function in older men and women after accounting for muscle size and adiposity. We hypothesized that neuromuscular activation would be a strong, independent factor explaining the inter-individual variability of walking speed among older males and among older females.

2. Methods

2.1. Participants

Volunteers between the ages of 70 and 85 years were screened according to the following exclusion criteria: acute or terminal illness, myocardial infarction within 6 months (or other symptomatic coronary artery disease), uncontrolled hypertension (>150/90 mm Hg), unstable chronic disease, lower extremity fracture in the previous 6 months, diseases or medications affecting neuromuscular function, hormone replacement therapy, body mass index <19 or >33 kg/m^2, weight loss or gain exceeding 10 lbs within the previous six months and participation in a strength or endurance training program within the previous six months. Individuals who passed the telephone screening were further screened by a licensed physician or nurse practitioner, including assessment of the presence of lower extremity joint pain and administration of the Mini Mental State Examination (MMSE) and Short Physical Performance Battery. Persons with MMSE score <23 or with substantial joint pain were excluded. This study is a secondary analysis of data from a larger research trial whose primary results have been published previously (Clark et al., 2011; Ronkainen et al., 2009). In the main research trial, two groups of older adults were enrolled. The higher functioning group had SPPB score >9 and used no prescription medications. The lower functioning group had SPPB ≤9. In the present study, we pooled these two groups in order to leverage the inter-individual variability for conducting a multivariate regression analysis of the determinants of mobility function. All volunteers provided written informed consent before participating in this study. All research procedures were approved by the Institutional Review Board of Tufts University and were in accordance with the Declaration of Helsinki.

2.2. Protocol and Instrumentation

Mobility function was assessed with the 400-m walk test. The test consisted of walking 10 laps around a pair of cones that were separated by 20 m. Participants were instructed to walk at their typical speed. To obtain speed, the 400 m distance was divided by the time to complete the test (in seconds), as recorded with a stopwatch.

Participants were then seated on a bilateral leg press apparatus and positioned such that the range of motion began with knees flexed to 90° and hips flexed to approximately 110°. The leg press apparatus provided adjustable resistance via pneumatic pistons attached to the footplate (Leg Press A420, Keiser Corporation, Fresno CA). Neuromuscular activation was assessed by surface electromyography (EMG) using a commercially available data acquisition system (Delsys Bagnoli-8, Delsys, Boston, MA). Single differential surface electrodes (Delsys 2.1, Delsys, Boston, MA) with 1 cm inter-electrode distance were placed over the muscle bellies of the rectus femoris (*rf*), vastus medialis (*vm*) and vastus lateralis (*vl*). Signals were recorded at a sampling rate of 1 kHz using a Powerlab/16SP A/D system and Chart software (ADInstruments, Colorado Springs, CO). Participants performed five maximal effort trials against a resistance equal to 260 N, which was close to the minimal resistance setting possible on the leg press apparatus. The low resistance ensured that even participants with considerable weakness would be capable of performing the task with proper form. Participants were instructed to push "as fast and as hard as possible" through the concentric phase of the movement and then slowly return the footplate to the starting position. Five trials were performed, with each trial separated by 30 s of rest and each resistance condition separated by at least 2 min of rest. Participants then performed 2–3 isometric maximal voluntary contraction (MVC) trials, with the leg press foot plate constrained to the starting position. The data presented here are from the second of two identical testing sessions performed approximately one week apart. The first session allowed participants to become familiar with our testing equipment and procedures.

Mid-thigh cross-sectional area of muscle, inter-muscular adipose and subcutaneous adipose tissues were quantified using computed tomography (CT). The length of the femur was determined from a coronal scout image as the distance between the intercondylar notch and the trochanteric notch. Scans were obtained using a Siemens Somotom Scanner (Erlangen, Germany) operating at 120 kV and 100 mA, with slice width of 10 mm and a scanning time of 1 s.

2.3. Data analysis

EMG data were analyzed using a custom analysis program created in MATLAB (version 7.0, The Mathworks, Natick MA). The analysis has been described in detail in our prior work (Clark et al., 2011). All raw EMG signals were de-meaned (i.e., signal mean was set to zero) and filtered with a zero phase lag first-order Butterworth band-pass filter (10–200 Hz). Peak EMG amplitude during isometric MVC was quantified as the root-mean-square over the 100 ms window containing the greatest amplitude. For dynamic trials, the rectified EMG signals were smoothed using a 100 ms sliding window average. The EMG signal from each muscle was then normalized to its own peak EMG from the MVC trial (Burden, 2010). The rate of EMG rise was calculated for each muscle (*rf*, *vm*, *vl*) as the mean derivative of the normalized EMG signal between activation onset and movement onset. The rate of EMG rise was then averaged across muscles to provide a composite measure for the quadriceps muscle group. We have previously shown that the rate of EMG rise is positively associated with force production, power production and mobility function (Clark et al., 2011, 2013).

All CT scans were analyzed by a single investigator who was blinded to the identity of the participants. Analysis was conducted with SliceOmatic v4.2 software (Montreal, Canada). Images were reconstructed on a 512 × 512 matrix with a 25-cm field of view. From the images, the cross sectional areas (CSAs) for muscle, intermuscular adipose tissue and subcutaneous adipose tissue were measured using manual tracing. Muscle CSA was measured in the range of 0–100 Hounsfield units (HU) and calculated as the sum of low-density muscle and normal-density muscle CSA. Adipose tissue areas were measured in the range of −190 to −30 HU. Intermuscular adipose tissue was defined as adipose tissue lying between and among muscle groups. These methods have been described previously (Goodpaster et al., 2001; Kelley et al., 1991).

2.4. Statistics

Data were analyzed using JMP statistical software (Version 9.0.2, SAS Institute Inc., Cary NC). Within each group (males and females), the predictors of 400 m walking speed were assessed using a multiple linear regression analysis. In order to determine the most appropriate multiple regression model(s), we first conducted an exploratory analysis using Pearson's correlation. This was done to assess the association between the dependent variable (400 m walking speed) and independent variables, as well as to assess potential multicollinearity between independent variables. Prior to running the multiple regression analysis, the independent variables were standardized within each group by subtracting the group mean and dividing by the group standard deviation. The distribution of the error residuals for each model was evaluated for normality.