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Age-related differences in rate of power development exceed differences in peak power

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ABSTRACT

Peak power (pP) declines during aging, resulting in reduced functional performance. However, the rate of power development (RPD) takes into account the short response times available during many functional tasks and may therefore add valuable information to functional declines. This study examined the age-related effects on pP and RPD of the knee-extensors across different loads and how these are related to functional performance.

36 young (♂21, ♀15, age = 22 ± 2 years) and 56 older adults (♂26, ♀30, age = 68 ± 5 years) performed four maximal isotonic contractions against three loads (40, 20 and 60% of maximal isometric strength) on a Biodex System 3 dynamometer. pP was calculated as the highest value and RPD as the linear slope of the power-time curve. Functional performance in the older group was tested by 7.5-meter fast walk, timed up-and-go and stair climbing.

pP and RPD were higher in young compared to old and this was more pronounced with lower loads. Age-related differences in RPD (range from 37 to 44% across loads) were higher than in pP (24–37%). Both pP and RPD showed a positive correlation with functional performance (r: 0.59–0.64).

To conclude, percent differences in RPD exceed differences in pP between young and old. This emphasizes the inability to generate power rapidly at older age and underlines the importance of time-dependent measures to detect age-related changes in muscle function.

1. Introduction

Human aging has been associated with declines in muscle strength and power (Charlier et al., 2015; Reid and Fielding, 2012). These age-related declines lead to a reduction in functionality, a higher risk of falls and a slower general movement pattern, jeopardizing the independency of older adults (Rolland et al., 2008). In order to prevent this loss of independence, a better understanding of aging of muscle function is required.

The majority of methodologies that evaluated muscle function in older adults focused on maximal strength, which is very important in daily tasks since this sets the reserve limit (Lauretani et al., 2003). However, maximal strength requires > 500 ms to be achieved (Hakkinen and Hakkinen, 1991). This makes it less functionally relevant in situations that require quick and powerful responses of muscles, such as balance recovery following sudden perturbations (Pijnappels et al., 2008). Parameters that reflect the ability to rapidly produce force, such as the rate of force development, correspond to the short response times that are normally available to accelerate the limbs during many functional tasks (i.e., less than ~200 ms) (Thompson et al., 2013; Aagaard et al., 2002; Maffiuletti et al., 2016). Previous research that focused on rapid isometric force production already demonstrated differences between young and older adults and its link to functional performance (Thompson et al., 2013; Aagaard et al., 2002; Maffiuletti et al., 2016; Thompson et al., 2014a; Clark et al., 2013; Izquierdo et al., 1999).

In comparison to isometric tests, dynamic tests have greater external validity to functional movements. More specific, power, i.e. the product of force and velocity measured during dynamic tests is more strongly related to functional performance than maximal isometric strength

Abbreviations: pT, peak torque; pV, peak velocity; pP, peak power; ttpV, time to peak velocity; ttpP, time to peak power; RVD, rate of velocity development; RPD, rate of power development

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(Reid and Fielding, 2012). In addition, power and velocity decline more than maximal strength during aging, leading to an age-related slowing of muscles (Reid and Fielding, 2012; Macaluso and De Vito, 2003). The age-related slowing of muscles suggests that older adults need more time to develop maximal velocity or power. This emphasizes the need to study muscle function in a time-dependent way, which would more closely reflect functional movements in older adults (Tillin et al., 2013). To date, few studies have focused on rapid force characteristics during dynamic actions (i.e. the rate of velocity (RVD) or power (RPD) development) and their relationship to functional capacity in older adults. Interestingly, Thompson et al. observed a greater difference in RVD compared to pV of the leg extensor muscles between young and older men (Thompson et al., 2014b). These findings underline the importance of the time to peak velocity (ttpV) and suggest that RVD can be more discriminatory between age-groups compared to pV.

The scarce research that investigated RVD using dynamometry focused on isokinetic and unloaded testing (Thompson et al., 2014b). However, most activities during daily life are variable in velocity and include loading. More similar to daily tasks, isotonic contractions include an acceleration component and a certain amount of loading (Power et al., 2011). Therefore, isotonic measures of power could serve as a better indicator for functional movements. Accordingly, isotonic testing has been emerging as a more functional though standardized method for the evaluation of muscle function (Dalton et al., 2010; McNeil et al., 2007; Valour et al., 2003; Dalton et al., 2012). This type of testing in the older population seems especially relevant for the knee extensors, given that these muscles are crucial in a number of functional and locomotor tasks (Ploutz-Snyder et al., 2002). To date, research using isotonic tests for knee-extensor muscle function in older adults is limited (Macaluso and De Vito, 2003; Dalton et al., 2012; Stauber and Stauber, 2000). Even more, no research has evaluated time-dependent isotonic knee-extensor function and its link to functional movements.

Therefore, the present study aimed at determining age-related differences in pV, pP, RVD and RPD of the knee-extensor muscles using the isotonic mode on a gold standard dynamometer. These differences were evaluated across different loads. Functional performance tests were included to investigate the functional relevance of pV, pP, RVD and RPD. We hypothesized that RVD and RPD would differentiate more between young and older adults compared to pV and pP respectively. In addition, we hypothesized that RPD would be more strongly related to functional performance in older adults than pV, RVD and pP.

2. Methods

2.1. Subjects

Baseline values of the participants of two intervention studies in our lab were used for this study (Van Roie et al., 2013a; Van Roie et al., 2013b). Subjects were community-dwelling and aged between 20–30 and 60–80 years. Exclusion criteria were (i) pathologies that prohibit a maximal strength test, such as severe cardiovascular disease, artificial hip or knee, acute hernia, infection or tumor and (ii) systematic engagement in endurance (i.e. no training with progressive increases in volume and/or intensity) or resistance exercise (i.e. no participation in the prior 12 months). Occasional engagement in physical activity, such as cycling, walking and running was allowed. Thirty-six young (♂21, ♀15, age = 22 ± 2 years) and fifty-six older adults (♂26, ♀30, age = 68 ± 5 years) volunteered. Young participants were apparently healthy and free of medication use. Based on self-reported health questionnaires, the older participants were classified into health categories following a classification system as described previously (Bautmans et al., 2004; Bautmans et al., 2005; Forti et al., 2014) in order to estimate the risk for complications during physical exercise. Subjects' characteristics are shown in Table 1. All subjects gave written informed consent. The study was approved by the University's Human Ethics Committee in accordance with the declaration of Helsinki.

2.2. Procedures

2.2.1. Dynamometry

Measurements of static strength as well as power of the knee extensors were conducted on the Biodex Medical System 3® dynamometer (Biodex Medical Systems, Shirley, New York, United States). The tests were performed unilaterally on the right side, unless there was a medical contraindication. This was the case for four older adults, who experienced injuries at the right leg in the past (e.g. knee pain or muscle rupture). None of them reported problems during daily activities, nor during the functional performance tests. Tests were solely performed on the left side for safety reasons. Participants were seated on a backward-inclined (5°) chair. The upper leg on the test side, the hips and shoulders were stabilized with safety belts. The rotational axis of the dynamometer was aligned with the transversal knee-joint axis and was connected to the point of force application at the distal end of the tibia using a length-adjustable rigid lever arm. Range of motion was set from a knee joint angle of 90° to 160°, with a fully extended leg corresponding to a knee angle of 180°. The test protocol, which was used in previous studies in our lab (Van Roie et al., 2013b), was conducted twice and included two standardized tests in the following order: isometric and isotonic tests. Isometric strength was assessed at a knee joint angle of 90°. Subjects were clearly instructed by the test leader to avoid an explosive contraction, but to extend their leg as hard as possible during 5 s, by building up strength gradually till maximal strength was reached. Two maximal isometric knee extensions, which were separated by a 20-second rest interval, were performed. Peak torque (pT, Nm) was recorded. The isotonic tests included ballistic knee extensions against constant resistances in the same specific order for every subject (i.e. consecutively 40%, 20% and 60% of maximum isometric strength). The subjects were clearly instructed by the test leader to extend their leg as fast as possible and then passively return the leg to the starting position (90°). Two explosive contractions were performed at each load. The velocity (°/s) and the torque produced (Nm) during the ballistic extension were recorded. The tests with the highest peak value of torque for the isometric tests and the highest peak value of velocity for the isotonic tests were used for further analyses.

2.2.2. Functional performance tests

The following tests, which varied in terms of strength and velocity characteristics, were performed in older adults: 7.5-meter fast walk test (7.5mFWT), timed up-and-go test (TUG) and stair climbing (STC). All tests were timed by hand. To test 7.5mFWT, participants walked a distance of 7.5 m as fast as possible without running (Clark et al., 2013). The best result as the shortest total time to walk 7.5 m of two performances was used. The TUG was performed by standing up from a standard armchair, walk a distance of 3 m, turn, walk back and sit down again as fast as possible without running (Bischoff et al., 2003). Subjects were free to choose left or right turn. The time in seconds was measured and the best result from two trials was used. To measure STC ability, participants were asked to climb a 12-step staircase as fast as possible. The best result in seconds of two performances was used.

2.3. Data analyses

Torque and velocity signals from all isotonic tests were sampled at 100 Hz and processed off-line using a commercial software package (Matlab R2015b, The MathWorks Inc., Natick, Massachusetts, United States). Instantaneous power (Nm/s) was calculated as the product of both torque (Nm) and velocity (rad/s). Peak power (pP, Nm/s) and peak velocity (pV, °/s) were determined as the highest values of the power and velocity curve respectively. Time to peak power (ttpP, s) and time to peak velocity (ttpV, s) were determined as the time from the start of the movement till pP and pV were reached. Rate of power development (RPD, Nm/s^2) and rate of velocity development (RVD, $°/s^2$) were calculated as the linear slopes from the start of the movement till