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Age-related decline in leg-extensor power development in single- versus multi-joint movements

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ABSTRACT

Rapid muscle characteristics, such as the rate of power development (RPD), are shown to decline more than maximal muscle characteristics during ageing in single-joint actions. However, functional disability is mainly the result of multi-joint lower limb failure. The complex activation patterns inherent to multi-joint actions and the deteriorating effect of age on that neural drive suggest a larger effect of age on RPD multi-joint. Yet, this is the first study that compared multi- with single-joint leg extension tests in terms of RPD across the adult life span and assessed its transferability to functional performance.

96 healthy adults (♂ 49, ♀ 47, age = 20–69 years) performed dynamic single-joint knee-extension tests on a Biodex System 3 dynamometer and multi-joint leg-extension tests on a custom-made device at low, moderate and high speed. Peak power (Ppeak) was calculated as the highest value of the power-time curve and RPD as the linear slope till isokinetic speed was reached. Functional performance was tested using squat jump height.

RPD showed greater age-related declines in multi-joint (−1.92%/year) versus single-joint (−1.42%/year) actions, which is in contrast with the finding of Ppeak (−0.77% vs. –1.04%/year). Squat jump height was more strongly associated with RPD multi-joint than single-joint (r = 0.77–0.82 vs. 0.44–0.61).

These results show greater age-related declines of RPD multi-joint versus single-joint and demonstrate its functional relevance. We believe that this finding may be of high importance for the detection and prevention of functional disability during ageing.

1. Introduction

One of the major problems in our ageing and graying society is the age-related loss of independence, resulting in enormous health care costs. This loss of independence, manifested by a decreased physical performance and an increased fall risk, is a consequence of the effects of ageing on neuromuscular function (Kennis et al., 2014; Madigan and Lloyd, 2005; Aagaard et al., 2010). Therefore, optimized screening and prevention methods for this neuromuscular decline are highly needed.

The majority of screening methods in research and clinical practice focused on maximal muscle strength or maximal muscle power (Goodpaster et al., 2006; Kostka, 2005; Yamauchi et al., 2009; Macaluso and De Vito, 2003). Maximal power production deteriorates more during ageing compared to maximal strength (Lanza et al., 1985; Skelton et al., 1994). Moreover, muscle power is a better determinant of functional capacity compared to muscle strength (Cuoco et al., 2004; Foldvari et al., 2000), which suggest that dynamic tests to evaluate power are preferred over isometric tests for screening of neuromuscular function. However, neither maximal strength nor maximal power take into account the time needed to be developed (i.e. > 300 ms). In other words, these variables may not be representative for the initial phase of very quick movements, such as the prevention of a fall after stumbling (Madigan and Lloyd, 2005; Pijnappels et al., 2005).

This initial phase of very quick movements is represented by parameters such as the rate of force (RFD) or power development (RPD). RFD, i.e. the ability to produce force rapidly, declines to a greater extent during ageing and is more strongly related to functional daily tasks and fall risk than maximal strength (Häkkinen et al., 1998; Thompson et al., 2013; Clark et al., 2013; Izquierdo et al., 1999). In line with these findings, a recent study in our lab demonstrated that the age-related

Abbreviations: peak power (Ppeak), rate of power development (RPD)

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declines in RPD exceeded the declines in maximal power (Ppeak) performed in dynamic contractions (Van Driessche et al., 2018a). Conjointly, we can conclude that older adults have even greater difficulty in developing strength or power rapidly than in reaching high peak values. However, most studies were limited to isolated single-joint movements, which may not be representative for most daily life activities that include multi-joint movements (Azegami et al., 2007).

Multi-joint movements primarily differ from single-joint movements through their complex neural activation and coordination patterns of agonist and antagonist/synergist muscles. This neural activation capacity, which is crucial for rapid force production in older adults (Klass et al., 1985), is detrimentally affected by ageing (Billot et al., 2014). Therefore, ageing may have a different impact on rapid force production in multi- versus single-joint movements. To date, few studies have focused on rapid force production in multi-joint actions. These studies were either limited to isometric tests or did not compare multi-joint to single-joint tests within the same cohort (Izquierdo et al., 1999; Allison et al., 2013; Thompson et al., 2018).

Therefore, this study investigated the effect of ageing on maximal and rapid muscle characteristics in dynamic single- and multi-joint actions across the adult life span. In addition, associations with a functional movement were evaluated. We hypothesized that: 1) RPD declines more than Ppeak in both test methods, 2) RPD declines more in multi-joint compared to single-joint movements and 3) multi-joint RPD is more strongly related to a functional movement than single-joint RPD.

2. Methods

2.1. Subjects

Men and women between 20 and 70 years old (n = 10 ♂ and 10 ♀ per decade) were recruited through advertisements and oral communications. Subjects completed a short medical history and activity questionnaire and were excluded in case of a cardiovascular disease or acute thrombosis, recent surgery, neuromuscular disease, infection or fever, diabetes or pregnancy and systematic strength or endurance training (i.e. progressive increases in volume and/or intensity) in the prior 6 months. Occasional engagement in physical activity, such as cycling, walking and running was allowed. In total, 96 healthy subjects (♂ 49, ♀ 47) aged between 20 and 69 years volunteered and their data were included for all analyses. All subjects provided written informed consent. The study was approved by the University's Human Ethics Committee in accordance with the declaration of Helsinki.

2.2. Design

This study had a cross-sectional design to reveal the effect of age, sex, speed and test method on upper leg neuromuscular function. Subjects performed two test sessions separated by a rest day to avoid fatigue. In the first session, familiarization with the multi-joint protocol was performed as a warming-up, followed by the single-joint protocol. The second session was performed at the same time of day as session one and led by the same investigator. Participants performed a warming-up on a bike ergometer at a self-determined submaximal resistance for 10 min, before performing the functional performance tests and the multi-joint protocol.

2.3. Single-joint testing

Neuromuscular function of the knee extensors was measured using a standardized protocol on a Biodex Medical System 3® dynamometer with a sampling rate of 100 Hz (Biodex Medical Systems, Shirley, New York, USA). Measurements were performed unilaterally on the right side, in a seated position on a vertically and horizontally adjustable backward-inclined (5°) chair. 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 upper leg, hips and shoulders were stabilized with safety belts. The rotational axis of the dynamometer was aligned with the transversal knee-joint axis and connected to the distal end of the tibia with a length-adjustable rigid lever arm. After warming-up, subjects performed four isometric knee-extension tests at 90° knee joint angle. They were instructed to push as hard as possible for 5 s, separated by a 20-second rest period. Next, after at least 2 min of rest, subjects performed a series of three consecutive maximal isokinetic knee extension movements at slow, moderate and high speed (i.e. 60, 180 and 300°/s). During each dynamic test, the subjects were clearly instructed by the test leader to perform the tests as fast and as hard as possible. The rest interval was 30 s between the three conditions.

2.4. Multi-joint testing

A modified isokinetic version of the Nottingham Power Rig (Bassey and Short, 1990) was built to measure neuromuscular function of the leg extensors. The force output was transmitted via a foot plate, lever and chain, which was fixed onto a motor-driven freewheel body and hub (Dura-Ace FH-7700, Shimano® Inc., Osaka, Japan). The technical details of the isokinetic dynamometer have been previously described (Koninckx et al., 2008). Briefly, the rotation speed of the lever arm was synchronized with the servo-controlled rotation of the motor axle (CM71 motor type combined with a Movidrive controller MDS60A, SEW-Eurodrive, Bruchsal, Germany) using a timing belt and two identical pulleys (Synchroforce HTD 925-5M CXP, Contitech, Germany). Torque values were measured by a torque transducer with an overall accuracy of < 0.25% (1703 series, Lebow® Products Inc., Troy, United States). A dSpace interface (dSpace-GmBH, Paderborn, Germany) was used for data streaming at 1000 Hz, with a real-time control program (Simulink, The Mathworks Inc., Natick, United States). Movement of the lever arm was initiated by surpassing a cut-off torque of 20% of maximal isometric single-joint strength inducing a low-level of pretension (i.e. 20–70 Nm) as previously recommended (Tillin et al., 2013). Measurements were performed unilaterally on the right side. Subjects were seated on a backward-inclined (5°) chair, which was vertically and horizontally adjustable. In addition, the lever arm was adjustable to allow standardization of the multi-joint range of motion. Range of motion was set from a knee joint angle of 90° to 160° and from a hip joint angle of 70° to 115°, with a fully extended leg corresponding to a knee and hip angle of 180° (Fig. 1). The hips and shoulders were stabilized with safety belts. The right foot was fully supported and fixed

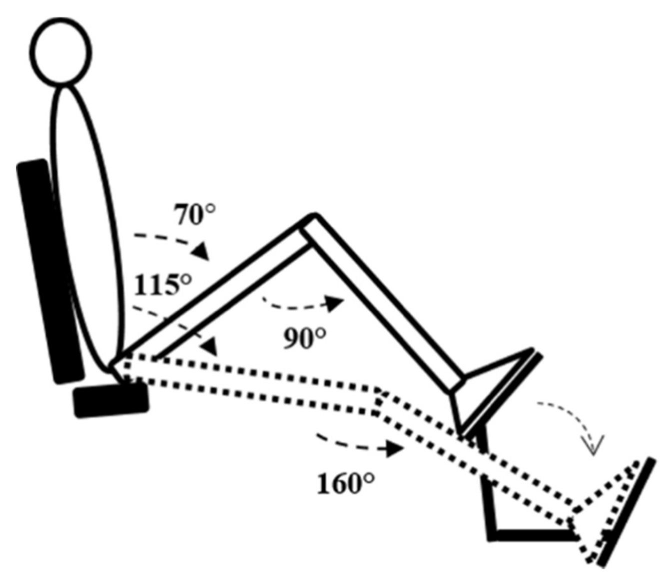

Fig. 1. Start and end position of the multi-joint leg press movement.