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Rate of power development of the knee extensors across the adult life span: A cross-sectional study in 1387 Flemish Caucasians

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ABSTRACT

A growing body of research in elderly populations suggests that the early phase of an explosive muscle contraction (i.e., ≤200 ms) may be more functionally relevant than peak values. However, age-related variation in early phase explosive strength has never been investigated across the full-adult life span. This cross-sectional study investigated the age-related changes in the rate of power development (RPD) and compared it to the changes in peak power (P_{peak}), both in terms of magnitude and onset, across the adult life span. Age-related declines in power and determinants of muscle power were compared between sexes.

1387 adults (♂813, ♀574), aged 18–78 years, performed three maximal isoinertial knee extensor tests at 20% of their isometric maximum on a Biodex dynamometer. P_{peak} was calculated as the highest value and RPD as the linear slope of the power-time curve. Velocity (v) and torque (T) at P_{peak} were registered.

In both men and women, the decline in P_{peak} and RPD was already apparent from 40 years onwards. Annual percent decline rates were greater for RPD (−1.1% for men and −1.3% for women) than P_{peak} (−0.9% for men and −1.0% for women). Velocity at P_{peak} showed the lowest annual percent decline rates (−0.3% for men and −0.4% for women). Men performed better than women on all parameters (all $p < 0.001$). Velocity at P_{peak} tended to decline more in women than in men ($p = 0.065$).

To conclude, both knee extensor P_{peak} and RPD can be used to screen for age-related neuromuscular weaknesses at an early age. Both sexes seem equally susceptible to age-related declines in knee extensor power. In addition to traditional slow-speed resistance exercise, prevention strategies should include explosive exercises. Explosive exercises may be especially relevant in women, considering that they tend to decline more in the velocity component of muscle power.

1. Introduction

Everyday activities, such as rising from a chair and climbing stairs, depend upon the lower limb muscles' ability to generate a certain amount of power (Skelton et al., 1994; Bean et al., 2002). Consequently, reduced muscle power has been proposed as an important predictor of age-related deterioration in functional capacity (Foldvari et al., 2000; Reid and Fielding, 2012). Progressive age-related declines in muscle power have been shown to exceed and even precede declines in maximal strength. While significant declines in maximal strength are typically reported from the age of 50 years onwards (Skelton et al., 1994; Baumgartner et al., 1998; Charlier et al., 2015), the onset of decline in muscle power is observed from the age of 40 years (Kostka, 2005). Therefore, power might be more sensitive as a screening method for the detection of early deterioration of neuromuscular function than maximal strength.

In previous ageing research using large sample sizes and wide age ranges, muscle strength and/or power have typically been evaluated in terms of peak outputs (Charlier et al., 2015; Kostka, 2005; Lindle et al., 1997; Lynch et al., 1999). However, a growing body of research in elderly populations suggests that the early phase of an explosive muscle contraction (i.e., ≤200 ms) may be more functionally relevant than peak values that need more time to be achieved (i.e. at least 300 to 500 ms in isometric conditions) (Clark et al., 2013; Hakkinen and Hakkinen, 1991; Thompson et al., 2013; Aagaard et al., 2002). This early phase of an explosive contraction is especially relevant in reactive motor tasks, such as balance recovery after tripping (Pijnappels et al., 2008). A typical outcome parameter that corresponds to this early phase (i.e., ≤200 ms) is the rate of force development (RFD) during a rapid voluntary isometric contraction (Maffiuletti et al., 2016). Even

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though previous research on RFD during isometric contractions has already demonstrated marked differences between young and old adults (Thompson et al., 2013), the functional value of isometric tests has often been questioned (Aalund et al., 2013). In daily activities, explosive force production is more often needed in activities that require concentric instead of isometric force. In addition, Tillin et al. suggested that the ability to use the muscle's explosive torque-producing capacity is influenced by contraction type, with explosive voluntary performance being superior during concentric than isometric contractions because of a greater neural drive to the agonist muscle (i.e. greater agonist root mean square EMG values normalized to maximal M-wave over the first 50 to 150 ms of contraction) (Tillin et al., 2012). Dynamic concentric contractions therefore seem more relevant than isometric contractions to evaluate early phase explosive strength. This is particularly the case for isoinertial conditions, in which the load is fixed and accelerations can vary, because of their similarity to functional movements. Another important difference in force production between isometric and concentric contractions is that concentric force production is not only influenced by the muscle's ability to activate the contractile elements quickly and to transfer this force to the bone, but also by the force-velocity properties of the muscle (Hahn et al., 2017). Accordingly, concentric measurements differ from isometric measurements in the requirement for muscle shortening and provide different information.

In a recent paper, Van Driessche et al. evaluated both the rate of power development (RPD) and peak power by means of isoinertial knee-extension tests on a conventional Biodex dynamometer. By comparing an older population to a young reference group they demonstrated that age-related differences in RPD exceeded differences in peak power, which emphasizes the added value of RPD in ageing research (Van Driessche et al., 2018a). However, to our knowledge, no research has evaluated RPD across the adult life span. A thorough examination of the magnitude and timing of age-related changes in power development would provide us with valuable insights into the effect of ageing on neuromuscular function so that intervention strategies can be optimized. Given that power development is defined by both contractile force and contraction velocity, a comprehensive description of the impact of ageing on these force-velocity components may yield crucial information to optimize detection and prevention strategies.

Currently, there is conflicting evidence in the literature as to whether age-associated changes in these components differ between sexes (Charlier et al., 2015; Lindle et al., 1997; Frontera et al., 1991; Yamauchi et al., 2010). Interestingly, Edwén et al. showed that middle-aged (35–55 years) and older (> 65 years) women demonstrate lower leg muscle power during a countermovement jump compared to men, mainly due to a reduced velocity component rather than a reduced force component (Edwen et al., 2014). This finding may have important implications in regards to functional decline in women, but should be confirmed in different settings.

Therefore, the aim of the present study was to investigate the age-related decline in RPD and to compare this decline to the decline in peak power, both in terms of magnitude and onset, across the adult life span. In addition, age-related declines in power and determinants of muscle power were compared between sexes.

2. Methods

2.1. Subjects

This cross-sectional study is part of a Flemish longitudinal study of which the sampling procedure was previously described in detail by Matton et al. (Matton et al., 2007). Subjects consisted of 18- to 78-year-old adults randomly selected within the community in Flanders, Belgium. Data collection took place between October 2002 and April 2004. All subjects went through a medical examination, anthropometric measurements, physical performance tests, and physical activity and health-related questionnaires. The exclusion criteria have been previously reported in detail (Wijndaele et al., 2007). Briefly, subjects were excluded in the case of cardiovascular disease or acute thrombosis, recent surgery, neuromuscular disease, infection or fever, diabetes and/or pregnancy. The current study focused on measurements of muscle strength and power. Data of 813 men and 574 women, aged 18 to 78 years, were included in the analyses. The study was approved by the University's Human Ethics Committee in accordance with the declaration of Helsinki. All subjects provided written informed consent.

2.2. Outcome measurements

The outcome measurements have been previously described (Wijndaele et al., 2007). Below, a concise overview is provided and procedures are further clarified where necessary.

2.2.1. Anthropometry

Body height (m) was measured to the nearest millimeter using a Holtain stadiometer (Holtain, Crymych, UK) and body mass (kg) was measured to the nearest 0.1 kg using a digital scale (Seca 841, Seca GmbH, Hamburg, Germany). Body Mass Index (BMI) was calculated as mass (kg) divided by squared height (m^2).

2.2.2. Muscle strength and power

2.2.2.1. Procedure. Force-velocity characteristics of the knee extensors were measured using a standardized protocol on a Biodex Medical System 3® dynamometer (Biodex Medical Systems, Shirley, New York, USA). Positioning of the subjects was fixed according to standardized procedures, as reported previously (Charlier et al., 2015). All tests were performed unilaterally on the right leg. The protocol consisted of two tests, performed in the following order: isometric followed by isoinertial tests. The best performances, i.e. the repetition with the highest torque for the isometric test and the highest velocity for the isoinertial test, were used for further analysis. Isometric knee extensor strength was assessed at a knee joint angle of 90° (with 0° corresponding to full extension). Subjects were instructed to extend their leg as hard as possible for 5 s. The test was conducted twice, separated by a 20-second rest interval.

Ballistic isoinertial tests were performed at a constant load of 20% of the maximal isometric strength at a 90° knee joint angle. Subjects were instructed to extend their leg as fast as possible from a knee joint angle of 90° to 20° and passively return to the starting position. Three repetitions were performed.

2.2.2.2. Signal processing. Torque and velocity signals were sampled at 100 Hz and processed offline using Matlab (The Mathworks Natick, USA). For the isometric test, the maximal voluntary contraction (MVC, Nm) was defined as the highest value of the torque-time curve. For the isoinertial test, instantaneous power (watt) was calculated as the product of torque (Nm) and velocity (rad/s) throughout the movement. Peak power was identified as the highest value of the power-time curve (P_{peak}, w), together with its constituting components, namely torque (T at P_{peak}, Nm) and velocity (v at P_{peak}, °/s). The knee joint angle at which peak power was reached was defined as the angle at P_{peak} (°). Time to peak power (ttP_{peak}, s) was defined as the time from the onset of the movement until peak power was reached. The rate of power development was determined as the linear slope of the power-time curve from the onset of the movement until peak power was reached (RPD; Δpower/Δtime; watt/s). The onset of the movement was defined as the point where the acceleration reached a threshold of $150°/s^2$. The reliability of this methodology in a sample of 63 older adults (65–85 years) was excellent; the ICC and CV (%) ranged from 0.90 to 0.98 and from 5% to 9% for all variables (Van Driessche et al., 2018b).