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AGE-RELATED DIFFERENCES IN EXPLOSIVE STRENGTH IN OPEN VS. CLOSED KINETIC CHAIN EXERCISES

STAROSTNE RAZLIKE V EKSPLOZIVNI MOČI PRI NALOGAH ODPRTE IN ZAPRTE KINETIČNE VERIGE

ABSTRACT

The decline in explosive strength and its functional significance in old age have been well established using open (OKC) and closed (CKC) kinetic chain exercises, but not simultaneously for both exercises. The purpose of the study was to compare the age-related decline in the ability to rapidly produce force (impulse in the first 200 ms) in OKC and CKC exercises.

Twenty young (YP; 24 ± 3 yrs) and 15 old (OP; 69 ± 4 yrs) participants performed an explosive isometric unilateral OKC exercise i.e. a single-joint knee extension on a rigid chair and a CKC exercise i.e. a multi-joint leg extension on a leg press machine.

There were significant differences between OP and YP for impulses in OKC and CKC ($p<0.01$ and $p<0.05$). In OKC, OP had ~ 42% lower torque impulses than YP and, when expressed relative to body mass, this difference increased to ~ 48% ($p<0.001$). In CKC, age-related differences for force impulses were smaller but still significant (~ 28%, $p<0.05$) and increased when expressed relative to body mass (~ 37%, $p<0.01$). A two-way ANOVA revealed the significant interaction effect of group and chain on the percentage of maximal impulse ($p<0.01$), that differences between OP and YP were preserved only in OKC (~ 27% lower in OP), while there were no differences between groups in the percentage of maximal impulse in CKC; ~ 7% lower in OP.

We conclude that the age-related loss of explosive strength is more affected in OKC than in CKC. Multi-joint movements are more related to functional movements of daily activities than single-joint ones and therefore appeared to be better preserved in old age.

Key words: ageing, knee extension, leg extension, single joint, multi-joint

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IZVLEČEK

Upad kakor tudi funkcionalni pomen eksplozivne moči v starosti je bil pogosto proučevan, vendar ne sočasno s testi odprte (OKV) in zaprte (ZKV) kinetične verige. Namen raziskave je bil primerjati kako se sposobnost hitrega razvoja sile (impulz v prvih 200 ms) pri nalogah OKV in ZKV spremeni s starostjo.

Dvajset mlajših (ML; 24 ± 3 let) in 15 starejših (ST; 69 ± 4 let) merjencev je z dominantno nogo eksplozivno izvedlo izometrični eno-sklepni izteg kolena na kolenski opornici (primer OKV) in izometrični več-sklepni izteg noge v nožni preši (primer ZKV).

Mlajši in starejši merjenci so se statistično značilno razlikovali v impulzu pri testu OKV kakor tudi pri ZKV ($p < 0.01$ in $p < 0.05$). Pri OKV so imeli ST ~ 42 % nižji impulz navora kot ML, ko smo impulz izrazili relativno glede na telesno maso, so se razlike povečale na ~ 48 %, $p < 0.001$. Pri testu ZKV so bile razlike med starostnima skupinama manjše, vendar še vedno statistično značilne (~ 28 %, $p < 0.05$), prav tako so se povečale, ko so smo jih izrazili relativno glede na telesno maso (~ 37 %, $p < 0.01$).

Dvosmerna ANOVA je pri deležu največjega impulza razkrila značilno interakcijo med faktorjema starostna skupina in kinetična veriga ($p < 0.01$), razlike med ML in ST so se ohranile le pri iztegu kolena (~ 27 % manjši impulz pri ST, $p < 0.01$), medtem ko se starostni skupini nista značilno razlikovali v deležu največjega impulza pri iztegu noge (~ 7 % manjši pri ST, $p = 0.37$).

Zaključujemo, da je s starostjo pogojena izguba eksplozivne moči večja pri OKV kot pri ZKV. Ker so več-sklepni gibi bolj povezani s funkcionalnimi gibi vsakdanjih aktivnosti kot eno-sklepni gibi, sklepamo, da se zato pri večsklepnih gibih kaže boljše ohranjanje eksplozivnosti v starosti.

Ključne besede: staranje, izteg kolena, izteg noge, več-sklepno, eno-sklepno

INTRODUCTION

Explosive strength plays an important role throughout life and is also vitally important in old age. Explosive muscle strength can be defined as the rate of rise in contractile force at the onset of contraction, i.e. the rate of force development (RFD) exerted within the early phase of rising muscle force (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Häkkinen & Komi, 1986). In addition to RFD, an important explosive strength parameter is the impulse that can be produced within a given contraction time (Aagaard, et al., 2002; Baker, Wilson, & Carlyon, 1994). It is well known that age-related loss of explosive strength is even greater than the loss of maximal strength; after the 6th decade of life the explosive strength decline is as high as 3–4%, whereas the decline in maximal strength is 1–2% per year (Petrella, Kim, Tuggle, Hall, & Bamman, 2005; Skelton, Greig, Davies, & Young, 1994). Greater age-related loss of explosive strength can mainly be attributed to a selective reduction in the number and size of type II muscle fibres (Lexell, Taylor, & Sjöström, 1988), the slowing of muscle contractile properties (Vandervoort & McComas, 1986) and reduced maximal motor unit discharge frequency (Kamen, Sison, Du, & Patten, 1995; Klass, Baudry, & Duchateau, 2008). According to Bassey and colleagues (1992), the decline of the leg extensors' explosive strength is an important limitation on the functional ability of frail elderly people (Bassey et al., 1992). Moreover, studies of frail elderly people found that, compared to maximal strength, explosive strength better predicts walking speed (Cuoco et al., 2004), the risk of falls (Perry, Carville, Smith, Rutherford, & Newham, 2007) and the risk of limited mobility (Bean et al., 2003). Similar observations were confirmed in community-dwelling older adults; leg power was found to be a strong predictor of functional status (Foldvari et al., 2000) and the risk of falls (Skelton, et al., 1994); moreover, lower extremity contraction velocity, but not strength, was found to be significantly associated with gait speed in older women (Sayers, Guralnik, Thombs, & Fielding, 2005).

Because of its importance, the explosive strength of the lower extremities is often included in different research and rehabilitation protocols for the elderly (Bassey, et al., 1992; Bosco & Komi, 1980; Izquierdo, Aguado, Gonzalez, Lopez, & Hakkinen, 1999). These protocols may include the isometric assessment of explosive strength using either open (OKC) (Clarkson, Kroll, & Melchionda, 1981; Klass, et al., 2008; Thelen, Schultz, Alexander, & Ashton-Miller, 1996) or closed kinetic chain exercises (CKC) (Allison, Brooke-Wavell, & Folland, 2013; Häkkinen & Häkkinen, 1991). In OKC testing, Klass and colleagues (2008) showed differences between young and old participants in the rate of torque development (absolute and relative to maximal voluntary contraction), while in other studies the differences between age groups were only detected in absolute values (Clarkson, et al., 1981; Thelen, et al., 1996). A similar discrepancy in results can be observed in reports on CKC testing; (Häkkinen & Häkkinen, 1991) found lower RFD in elderly (absolute and relative to maximal voluntary contraction) while others were only able to detect differences between young and old participants in absolute RFD (Allison, et al., 2013).

In OKC testing, muscles work across only a single joint, which poorly reflects complex actions in daily activities (Augustsson & Thomeé, 2000). On the other hand, CKC testing using multi-joint actions includes more complex intra-muscular and extra-muscular coordination of agonist and antagonist muscles (Stensdotter, Hodges, Mellor, Sundelin, & Häger-Ross, 2003). To date, the majority of research investigating the decline of explosive strength in old age has focused on isolated single joint movements (Clarkson, et al., 1981; Klass, et al., 2008; Thelen, et al., 1996). The purpose of this study was therefore to assess whether age-related loss varies between open (isometric single-joint knee extension) and closed kinetic chain movements (isometric multi-joint leg extension).

MATERIALS AND METHODS

Participants

Twenty young participants (YP, 12 men and 8 women, range 19–30 years) and 15 older participants (OP, 8 men and 7 women, range 64–76 years) volunteered to participate in the study (Table 1). All participants completed a health and physical activity questionnaire and were included in the study if they were healthy and had no neuromuscular or orthopaedic disorders. Additional inclusion criteria were being moderately active (30–60 minutes of physical activity 2–3 times per week) and not participating in any systematic training regime at the time of the study.

For the elderly people, an additional inclusion criterion was the result of a standardised 30 second chair stand test that had to be between the 25^{th} and 75^{th} percentile for their age group (i.e. 12–18 stands for men and 10–16 stands for women) (Rikli & Jones, 2001).

All participants gave their informed consent to the procedures of the study and were informed about possible risks of the experimental protocol. The study was conducted according to the Declaration of Helsinki and approved by the institutional ethics review board of the Faculty of Sport in Ljubljana.

Experimental overview

The participants visited the laboratory on two occasions, each separated by one week. The first visit was an orientation session to allow for familiarisation with the experimental apparatus and protocol. On that occasion, personal data were gathered (age, height, weight along with the health and physical activity questionnaire), and we also determined the participants' dominant leg; the participant was standing up straight and took a step forward, the leg that took the first step was considered dominant. On the second visit, the main measurements of explosive actions were carried out. After a standardised warm up (6 min stepping on a 20 cm high bench at a constant pace of 0.5 Hz), the participants performed two types of explosive isometric contractions in a random order: a single-joint knee extension – OKC exercise and a multi-joint leg extension – CKC exercise. All muscle actions were performed with one (the dominant) leg. Before the explosive contraction, the participants had to develop a certain level of pre-activation (~20% of maximal force) and after that contract "as fast and forcefully as possible" and maintain the maximal force for 2 seconds. Verbal encouragement was provided between each contraction. A subject had an online visual feedback of the dynamometer on a computer screen. Trials with an initial countermovement (identified by a visual drop in the force signal) were always disqualified and a new trial was performed. Three repetitions for each condition were performed with an interval of 2 min between trials.

Single-joint knee extension measurement – OKC

The knee extension was done on a rigid chair (custom design) (Figure 1), equipped with a dynamometer (force sensor, MES, Maribor, Slovenia). The participants were in a seated position (i.e. the hip and knee joint angle was 90°). The back was supported and the hips were firmly fixed, the rotational axis of the dynamometer was visually aligned to the rotational axis of the knee (i.e. lateral femoral epicondyle) and the lower leg was attached to the dynamometer lever arm just above the ankle joint. The angle in the hip and knee joint was 90°. The participants were also instructed to hold onto the arm supports on both sides of the knee extension machine.

Multi-joint leg extension measurement – CKC

The leg extension was carried out on a commercial leg press machine (Armstrong, Dolenjske Toplice, Slovenia) equipped with a force plate (9253A11, Kistler, Winterthur, Switzerland) perpendicular to the direction of the sledge (Figure 2). The participants were placed in a semi-lying supine position (i.e. the hip and knee joint angle was 90°) and instructed to place their foot on the force platform, while keeping the plantar surface of their foot flat on the plate throughout the contraction. The opposite leg had to be held in a relaxed position without support. The participants were also instructed to hold onto the arm supports on both sides of the leg press machine.

Figure 1: The isometric knee extension dynamometry

Figure 2: The isometric leg press dynamometry

Experimental variables and data analysis

Torque during the single-joint and force during the multi-joint extensions were recorded at 2,000 Hz (DasyLab, National Instruments, Austin, USA). Accordingly, explosive strength was calculated as torque (IMT) and force impulse (IMF) in the first 200 ms interval (i.e. the area under torque – time curve and force – time, respectively) (Figure 3) and thus in line with previous studies (Aagaard, et al., 2002; Baker, et al., 1994). In addition, maximal impulse was analysed at the peak torque and peak force value during the explosive knee and leg extensions (± 100 ms). Impulses were analysed with the LabChart program (ADInstruments, Bella Vista, Australia) for each trial. The average of three trials was computed and used for further analysis. The onset of force was identified with visual inspection (Allison, et al., 2013; Clark et al., 2011). Signals were analysed by the same investigator by applying the same field of view to each contraction. Impulse was analysed as an absolute value (Nms or Ns, respectively), relative to body mass (IMT_{BM} (Nms/

kg) or IMF_{BM} (Ns/kg), respectively) and relative to maximal impulse (IMT_{MAX} (%) or IMF_{MAX} (%), respectively).

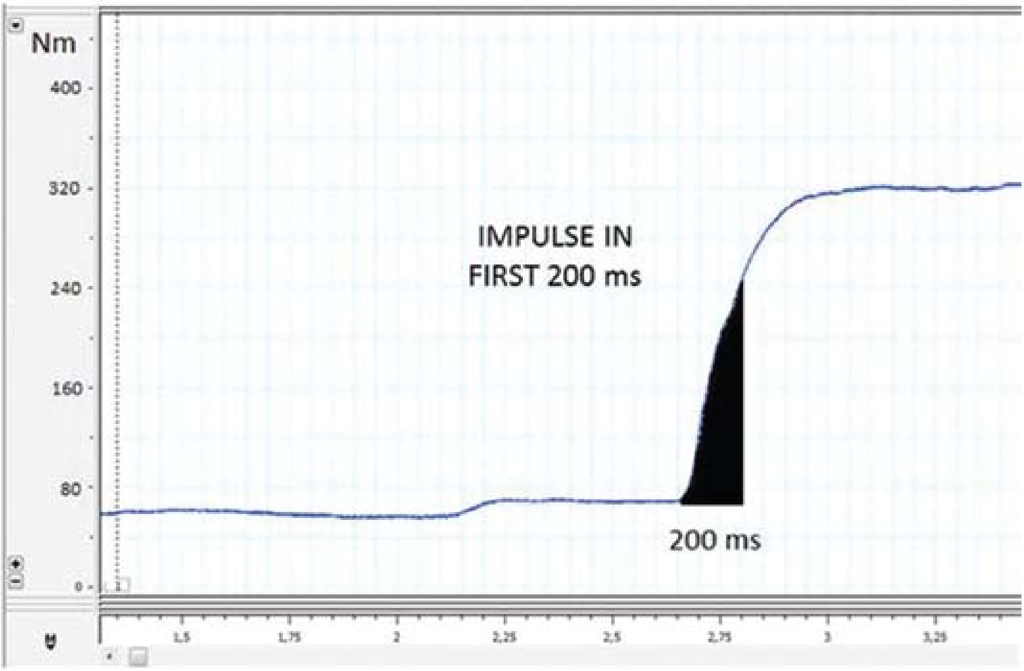

Figure 3: An example of a torque signal in an explosive isometric knee extension for a single young participant. Torque impulse was measured for the first 200 ms. The same was done for force impulse in an explosive isometric leg extension.

Statistical analysis

The data in the text and figures are presented as mean ± SD. A two-way repeated measures analysis of variance with one within- (chain) and one between-subjects factor (group) was used to test the differences in impulses expressed as maximal impulse values. When a significant main effect was found, the Newman Keuls post hoc test was applied to find the location of the difference. One-way ANOVAs were used to test the differences between OP and YP in all other dependent variables. Statistica 6.0 (StatSoft, Inc., Tulsa, USA) was used, and the level of significance for all comparisons was set at $p<0.05$. Effect size was also calculated for all variables using eta squared (η^2).

RESULTS

The physical characteristics of the young and old participants are presented in Table 1. There were no significant differences between YP and OP for height ($p = 0.070$) and body mass ($p = 0.132$). In contrast, BMI was significantly lower in YP compared to OP ($p<0.001$).

Table 1: Physical characteristics of the young (YP, n = 20) and old participants (OP, n =15)

	YP young participants	OP old participants
Age (years)	23.9 (3.3)	69.1 (3.7)***
Height (cm)	176.4 (7.7)	170.7 (10.2)
Body mass (kg)	72.1 (11.8)	79.0 (14.8)
BMI (kgm^{-2})	23.1 (2.5)	26.9 (3.0)***

Legend: BMI – body mass index; asterisks denote a significant difference compared to young participants (***p<0.001)

The strength characteristics of the young and old participants are presented in Table 2. There were significant differences between YP and OP for peak force (CKC; p<0.01), while the differences between YP and OP for peak torque (OKC; p=0.058) were on the verge of significance.

Table 2: Strength characteristics of the young (YP, n = 20) and old participants (OP, n = 15)

	YP young participants	OP old participants
Peak torque (Nm) in OKC	184.0 (59)	144.0 (61)
Peak force (N) in CKC	1168 (311)	880 (257)**

Legend: OKC – open kinetic chain exercise (knee extension), CKC – closed kinetic chain exercise (leg extension); asterisks denote a significant difference compared to young participants (**p<0.01)

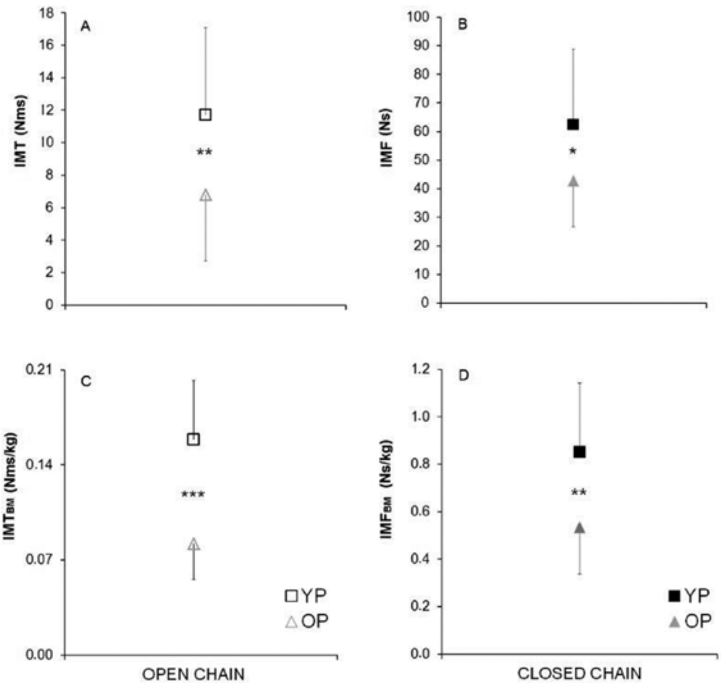

Figure 4: Torque impulse for open chain exercise (panel A) and force impulse for closed chain exercise (panel B) and their values expressed relative to body mass (panels C and D) (YP – young participants, OP – old participants, *p<0.05, **p<0.01, ***p<0.001).

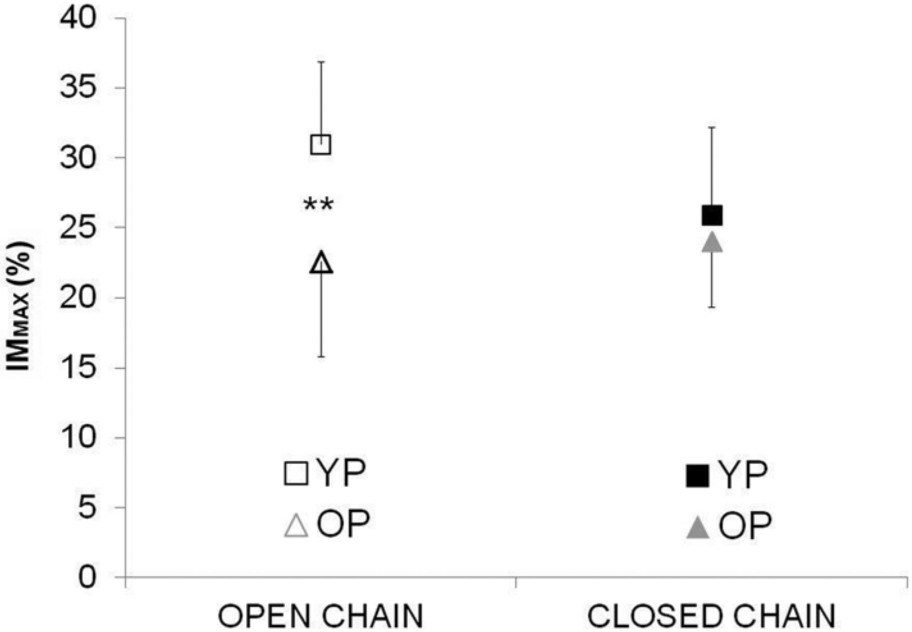

Figure 5: Impulse expressed as a percentage of maximal impulse for the open and closed chain exercises (squares (open and closed) young participants, triangles (open and closed) old participants, **p<0.01).

There were significant differences between OP and YP for impulses in OKC and CKC (Figures 4A and B; $p<0.01$ and $p<0.05$). In OKC, OP had ~ 42% lower torque impulses (IMT) than YP and, when torque impulse was expressed relative to body mass (IMT_{BM}), this difference increased to ~ 48%, $p<0.001$ (Figure 4C). The ANOVA effect size (η^2) for IMT in OKC was 0.21, while for IMT_{BM} η^2 it was 0.37.

Age-related differences for force impulses (IMF) in CKC were minor, but still significant (~ 28%, $p<0.05$; Figure 4B) and in a similar manner were more pronounced when expressed relative to body mass (IMF_{BM}) (~ 37%, $p<0.01$; Figure 4D). The ANOVA effect size for IMF in CKC was 0.16, whereas for IMF_{BM} η^2 it was 0.29.

Expressing impulses as a percentage of maximal impulse (IM_{MAX}) enabled a direct comparison between OKC and CKC. A two-way ANOVA revealed the significant effect of the group × chain interaction on the percentage of maximal impulse ($F_{(1, 33)}= 14.3$; $p<0.01$, effect size 0.3). It is interesting to note that differences between OP and YP were only preserved in OKC (Figure 5; ~ 27% lower in OP; $p<0.01$), while there were no differences between groups in IM_{MAX} in CKC (Figure 5; ~ 7% lower in OP; $p=0.37$).

DISCUSSION

The aim of this study was to analyse differences in open (isometric single-joint knee extension) and closed kinetic chain exercises (isometric multi-joint leg extension) between young and old adults to assess the effect of ageing on explosive strength. The main findings were: (1) the young group exerted significantly greater impulses (IMT and IMF) in both exercises, with the differences being slightly more pronounced in OKC (~ 42% lower in the old participants, $p<0.01$) than in CKC (~ 28% lower in the old participants, $p<0.05$); (2) age-related differences increased when impulses were normalised to body mass (IMT_{BM} and IMF_{BM}) in OKC (~ 48% lower in the old participants; $p<0.001$) and in CKC (~37% lower in the old participants; $p<0.01$); (3) when impulses were expressed relative to maximum (IM_{MAX}), age-related differences diminished in CKC (Figure 5; ~ 7% lower in the old participants ($p=0.37$), but still present in the OKC exercise (Figure 5; ~ 27% lower in the old participants; $p<0.01$).

Age-related differences in the OKC and CKC explosive strength testing obtained in our study protocol are in line with two recent studies (Allison et al. 2013; Klass et al. 2008). Allison and colleagues (2013) showed that the explosive isometric strength of multi-joint leg extension (peak rate of force development) was 21% lower in older men, while Klass et al. 2008, who studied the age-related decline in the rate of torque development in a single-joint ankle dorsiflexion, found ~48% lower values in old men compared to young men. Moreover, we had expected that explosive strength differences between the groups would remain in the OKC and CKC testing due to the greater age-related loss in explosive compared to maximal strength (Petrella, et al., 2005). To our surprise, age-related differences diminished in the CKC testing when force impulse was expressed relative to its maximum value. If age-related reduction of explosive strength were solely due to the loss of muscle mass (Doherty, 2003; Lexell, et al., 1988) and a decrease in maximal discharge frequency (Kamen, et al., 1995; Klass, et al., 2008), we would expect it to be similar in OKC and CKC. Accordingly, it is possible that the reduced IM_{MAX} for OKC is also influenced by other factors, as stated below.

Factors explaining the different age-related explosive strength decline in OKC than in CKC in the present study could include the fact that OKC exercise entails a single-joint muscle action, which poorly resembles functional performance (Augustsson, Esko, Thomeé, & Svantesson, 1998), whereas CKC exercises are considered more functional and closely simulate daily activities (Allison, et al., 2013; Stensdotter, et al., 2003). The daily activities of elderly people are mostly closed kinetic chain movements (rising from a bed, chair, ascending stairs, walking, stepping to regain balance…), accordingly IM_{MAX} CKC could be preserved to a higher degree than IM_{MAX} OKC due to greater stimulation in everyday life.

Moreover, Petrella et al. (2005) speculated that the antigravity quadriceps muscle group may atrophy with age faster than the remaining thigh musculature. They compared strength in dynamic knee extension, leg press and squat; after adjusting the strength for thigh lean mass, the age-related declines were minimised (no longer significant) for the leg press and squat, although age differences in maximal knee extension specific strength persisted. The different rate of atrophy of muscles included in the OKC and CKC tasks could partly explain the difference in the IM_{MAX} decrement. Although no data have been published to support these speculations of more accelerated effects of sarcopenia of the quadriceps muscle, it is worth noting that preferential quadriceps atrophy occurs in knee osteoarthritis and joint injury (Hurley, Jones, & Newham, 1994; Stevens, Mizner, & Snyder-Mackler, 2003), which are more present at older ages. Although the participants in our study had no pathologies or knee injuries, potential selective quadriceps atrophy deserves further attention.

The limitation of the present study was the relatively small sample size and that, for a more accurate and correct estimate of explosive strength loss with ageing, a longitudinal study should be conducted instead of the cross sectional design used in this study. It is worth taking into consideration that some inclusion criteria (health status, moderate activity level, absence of orthopaedic disorders…) along with voluntary participation could influence the sample of elderly people, making it healthier and fitter than the population. We tried to minimise the mentioned bias with additional inclusion criteria (a functional test that fitted the participants in the population).

In conclusion, to our knowledge this is the first study to compare differences in explosive strength between young and old people in OKC and CKC. This study demonstrated that age-related declines in the explosive strength of the lower extremities are more substantial in OKC (single-joint knee extension) compared to CKC (multi-joint leg extension). The differences in the stronger preservation of explosive strength in CKC compared to OKC may be related to the greater presence of CKC actions in day-to-day activities. In addition, our findings open questions for further investigations; the relationship of open and closed kinetic chain testing to functional performance in the elderly should be analysed. Based on those findings, it would be possible to advise when to include OKC and/or CKC in testing protocols and training regimes.

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