Age-Related Differences in Maximal and Rapid Torque Characteristics of the Hip Extensors and Dynamic Postural Balance in Healthy, Young and Old Females

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Abstract

Palmer, TB, Thiele, RM, and Thompson, BJ. Age-related differences in maximal and rapid torque characteristics of the hip extensors and dynamic postural balance in healthy, young and old females. *J Strength Cond Res* 31(2): 480–488, 2017—The purpose of this study was to examine age-related differences in maximal and rapid torque characteristics of the hip extensor muscles and dynamic postural balance in healthy, young and older females. Eleven younger (age, 26 ± 8 years) and 11 older (age, 67 ± 8 years) females performed 2 isometric maximal voluntary contractions (MVCs) of the hip extensor muscles. Absolute and relative peak torque (PT) and rate of torque development (RTD) at early (0–50 ms) and late (0–200 ms) phases of muscle contraction were examined during each MVC. Dynamic postural balance was assessed using a commercially designed balance testing device, which provides a measurement of dynamic stability based on the overall stability index (OSI). Results indicated that absolute PT and early (RTD50) and late (RTD200) RTD variables were lower ($p = 0.009–0.050$), and postural OSI was higher ($p = 0.011$) in the old compared with the younger females; however, no differences were observed for relative PT or RTD variables ($p = 0.113–0.895$). A significant relationship was also observed in the older ($r = -0.601$; $p = 0.050$) but not the younger ($r = -0.132$; $p = 0.698$) females between RTD50 and OSI. The lower absolute PT and RTD and higher OSI values for the old females may contribute to the increased functional limitations often observed in older adults. The significant relationship observed in the older females between OSI and RTD50 perhaps suggests that these age-related declines in explosive strength may be an important characteristic relevant to dynamic balance scores, especially in older populations.

Key Words strength, isometric testing, hamstrings, falls risk, stability, elderly

Introduction

The population of older adults (aged 65 years and over) in the United States is growing at an unprecedented rate (25) and is projected to more than double from 40 million to an estimated 87 million (~20% of the population) by the year 2050 (54). This increase in the number of older Americans has prompted intense research into age-related differences on neuromuscular performance and its functional consequences (14). Age-related changes in neuromuscular performance characteristics (i.e., declines in muscle mass, quality, strength, power) have been suggested to result in impaired locomotor function (29) and independence (53), which may subsequently lead to a deterioration in health and quality of life (17) and an increased risk for mortality (28).

Previous studies investigating age-related differences in maximal isometric strength values (i.e., peak force or torque [PF or PT]) have reported 14–46% reductions in these characteristics for a variety of different muscle groups, including the leg extensors (12,19,24,49), leg flexors (49), and plantar flexors (4,46,48). Despite these substantial declines, however, it has been demonstrated that age-related decreases in rapid strength characteristics (i.e., rate of force or torque development [RFD or RTD]) (25–68%) may exceed those in maximal isometric strength (24,27,46,48). These findings are critical considering that the ability to generate torque rapidly plays an important role in many locomotor-related movement tasks including the recovery from losses of balance to avoid falls (5,31,48). In fact, because many of these tasks involve movement durations of less than 200 milliseconds (26,30,47), rapid strength may be more functionally relevant, especially for older adults (49), compared with maximal

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strength characteristics, which typically require >300 milliseconds to be achieved (3,52). A number of studies have presented evidence in support of this hypothesis by demonstrating the superior ability of RTD vs. PT to discriminate between individuals of different fall histories (i.e., fallers vs. nonfallers) (31) and functional performance abilities (33,37,44). For example, Palmer et al. (33) recently showed that rapid torque characteristics within the early (≤50 ms) phases of muscle contraction were better discriminators of chair-rise performances than maximal torque and later (≥200 ms) rapid torque characteristics of the leg extensor and flexor muscles in healthy, very old males and females. Thus, given the importance of rapid torque production for many activities of daily living, it is likely that a reduction in RTD (or RFD) with aging may have a profound impact on the functional task performance and physical limitations of older adults (49).

The impact of neuromuscular aging is not only restricted to maximal and rapid isometric strength performances but also has an effect on static (9) and dynamic postural balance (14). For example, Wolfson et al. (55) reported that dynamic balance, as measured during an upright stance on a moving computerized platform, was adversely influenced by age such that older adults generated greater sway values, and therefore lower balance control than younger adults. Moreover, given the relationship between dynamic stability and balance recovery performances (6), dynamic balance may also play an important role in identifying individuals who may be at a higher risk for sustaining falls and fall-related injuries. Although it remains unclear as to the exact mechanisms underlying the increased falls risk and inferior balance that is typically observed in old compared with younger adults, previous studies (5,19,45) have suggested that the inability to produce torque rapidly may be a limiting factor in the performances of balance-related tasks. Sundstrup et al. (45) showed that a reduction in rapid torque capabilities of the leg extensor muscles in untrained old compared with younger adults was accompanied by a corresponding decrease in postural balance. In addition, Izquierdo et al. (19) demonstrated age-related balance and strength deficits in old vs. young males and a significant relationship in older males between peak RFD of the leg extensor muscles and dynamic postural control. However, these authors did not examine the relationships between dynamic postural control and early nor later RFD variables. Moreover, this study only examined males and because females are generally weaker than males across all age groups (12), it is possible that these differences may yield varying results between genders for balance and RTD-based relationships. Therefore, although rapid torque and/or force production of the lower-body musculature may be a significant contributor to dynamic balance performance and possibly may be used as an indicator for fall- and balance-related injury risk in healthy- and clinical-based male populations, research in young and older females is limited.

Most of the previous studies investigating age-related differences in maximal and explosive strength and postural balance characteristics among young and older adults have primarily examined the leg extensor and plantar flexor muscle groups (19,36,45). However, we are unaware of any previous studies that have investigated age-related changes in maximal and rapid torque and balance characteristics among young and older females involving the hip extensor muscles. This is somewhat surprising considering the functional importance of these muscles for postural balance control (32), as well as for their relevance in maintaining postural stability during a slip or a trip to avoid a fall (37). In addition, the hip extensors have also been reported to be an effective and sensitive discriminator of athletic-related performances (32) and a large contributor in many important locomotor-related tasks (8,10,50). Thus, given the importance of these muscles to many functional-specific movements, and the relationships between strength-based parameters, aging, and balance-related performances; further research is warranted examining the potential effects of using maximal and rapid isometric torque characteristics of the hip extensors and postural balance performance to characterize age-related changes in neuromuscular function of a healthy, active female population. Moreover, because older individuals have been reported to use more hip extension power and movement strategy (i.e., double-inverted pendulum or hip strategy) than younger individuals who rely on ankle plantarflexion movements (i.e., single-inverted pendulum or ankle strategy) to maintain postural stability (during gait or quiet standing) (18,42), it is possible that a stronger correlation may exist between rapid torque production of the hip extensor muscles and dynamic balance in old compared with younger adults; however, further research is needed to confirm this hypothesis. Therefore, the purpose of this study was to examine the influence of aging on maximal and rapid isometric torque characteristics of the hip extensor muscles in healthy, physically active young and older females. A secondary aim of this study was to compare dynamic balance scores (as measured during a falls risk assessment) between the 2 groups and to examine the relationships between these scores and maximal and rapid torque production.

Methods

Experimental Approach to the Problem

A cross-sectional research design was used to investigate age-related differences in dynamic postural balance and maximal and rapid torque characteristics of the hip extensor muscles in healthy, young and older females. Declines in postural balance and maximal and rapid torque production of the leg extensors and plantar flexors have been reported as a consequence of aging (19,36,45); however, we are aware of no studies to date that have investigated the influence of aging on these variables involving the hip extensor muscles. Thus, healthy, young and older females performed isometric strength testing of the hip extensors and a falls risk test to assess maximal and rapid isometric torque characteristics and dynamic postural balance, respectively. It was hypothesized that maximal and explosive strength would be lower and postural sway would be higher in the old compared with the younger females, and that rapid torque development in the older females would also be related to dynamic postural balance.

Subjects

Eleven younger (mean ± *SD*; age = 26 ± 8 years; height = 161 ± 8 cm; mass = 76 ± 22 kg; body mass index [BMI] = 29 ± 7 $kg \cdot m^{-2}$) and eleven older subjects (age = 67 ± 8 years; height = 158 ± 6 cm; mass = 68 ± 10 kg; BMI = 27 ± 3 $kg \cdot m^{-2}$) healthy females volunteered to participate in this study. Younger participants were recruited from the university environment and older participants were recruited from a community-based health and wellness facility. Each participant completed a self-administered questionnaire before testing to assess their health history, volume of physical activity, menstruation status, and hormone/contraceptive usage. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints. Participants were considered as being recreationally active based on their self-reported levels of aerobic (young = 4.1 ± 3.2 $hours \cdot week^{-1}$, old = 4.8 ± 4.5 $hours \cdot week^{-1}$) and resistance (young = 0.6 ± 1.2 $hours \cdot week^{-1}$, old = 1.7 ± 1.5 $hours \cdot week^{-1}$) exercise behaviors. Older females were all postmenopausal and were not taking any hormone replacement therapy. Younger females were not taking any form of oral contraceptives and none of them were menstruating at the time of testing. This study was approved by the university's institutional review board for human subjects research, and each participant read and signed an informed consent document.

Procedures

Each participant reported for testing on 2 separate occasions, separated by 2–3 days. During the first visit, participants were familiarized with the testing procedures by performing several falls risk and isometric hip extension strength assessment trials. During the second visit, participants completed 2 falls risk tests followed by 2 isometric strength assessments of the hip extensors.

Isometric Strength Testing

These hip extension isometric strength testing procedures have been described previously (34); however, these procedures will be briefly discussed below. A manual isometric strength assessment technique was used to quantify the maximal and rapid isometric torque characteristics. This technique consisted of the participant extending the thigh toward the floor against a load cell (LCHD-250; Omega Engineering, Inc., Bridgeport, NJ, USA) attached immediately posterior to the heel (Figure 1). For each isometric strength assessment, participants laid in a supine position with restraining straps placed over the waist and left thigh. The knee was braced in full-extension and the ankle was immobilized in a neutral 90° position (between foot and leg) with a custom-made cast that was fixed around the foot and secured with straps placed above the ankle and over the toes and metatarsals. All assessments were performed on the right leg at a hip joint angle of 20° above the horizontal plane, which was consistent with the hip joint angle for the isometric hip extensor strength assessment previously reported by Perry et al. (35). Before the maximal isometric strength testing, participants performed 3 submaximal isometric hip extension muscle actions at approximately 75% of their perceived maximal strength. After the submaximal contractions, each participant performed 2 isometric maximal voluntary contractions (MVCs) of the posterior muscles of the hip and thigh with 1 minute of recovery between each contraction. For all isometric MVCs, participants were verbally instructed to extend the thigh "as hard and fast as possible" for a total of 3–4 seconds and strong verbal encouragement was given throughout the duration of the MVC (34).

Assessment of Falls Risk

Falls risk assessments were performed using a Biodex Balance System SD (Biodex Medical Systems, Inc., Shirley, NY, USA), which provides a measurement of dynamic stability based on the overall stability index (OSI), determined as the variance in platform displacement from the horizontal plane (2). For all testing, participants removed their footwear and stood on the platform of the balance system with feet approximately shoulder-width apart and hands positioned on the hips (32). For each assessment, the "fall risk test" protocol was used according to the manufacturer's guidelines (7), in which participants were instructed to look "straight ahead" and maintain the platform, which was programmed to gradually become less stable (level 12 to level 8 stability), in "as level a position as possible" for 20 seconds. The calculation of OSI involved

Figure 1. An example of the manual hip extension isometric strength assessment setup. Participants were verbally instructed to extend the thigh toward the floor "as hard and fast as possible" against a load cell attached immediately posterior to the heel for 3–4 seconds.

recording the position of each participant's foot using the coordinates on the platform's grid (participants initially positioned their feet at suggested coordinates based on their height and then small adjustments were made to the heel position and foot angle until the center of pressure as indicated by the cursor was positioned in the middle of the grid on the computer screen) and entering it into the balance system computer, and subsequently deriving the OSI value, which was calculated and displayed by the computer at the conclusion of each assessment. Three falls risk assessments were performed with 10 seconds of rest between trials, and the average OSI of the 3 trials was used for all subsequent analyses. A recent study by Gusi et al. (15) demonstrated that the fall testing procedures and OSI data generated by the Biodex Balance System provided a reliable (intraclass correlation coefficient [ICC] = 0.89; standard error of measurement [SEM] expressed as a percentage of the mean = 17.3%) and valid balance measurement screening tool for identifying falls risk.

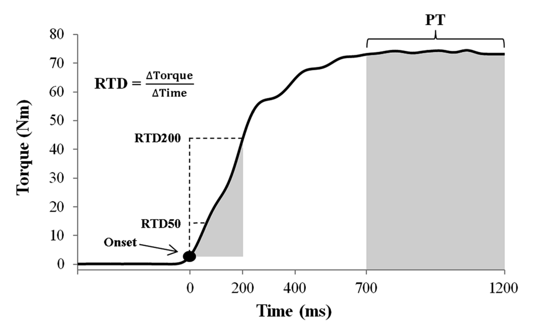

Figure 2. An example of a torque-time curve tracing taken from a young female during an isometric maximal voluntary contraction of the hip extensor muscles. Peak torque (PT; N·m) was determined from the highest 500-millisecond epoch. Rate of torque development (RTD; N·m·second^{-1}) was determined from the linear slope of the torque-time curve at time intervals of 0–50 (RTD50) and 0–200 (RTD200) milliseconds from onset.

Signal Processing

During each isometric strength assessment, the force (N) signal was sampled from the load cell at 1 kHz (MP100WSW; Biopac Systems, Inc., Santa Barbara, CA, USA), stored on a personal computer (Dell Inspiron 8200; Dell, Inc., Round Rock, TX, USA), and processed off-line using custom-written software (LabVIEW, Version 11.0; National Instruments, Austin, TX, USA). The scaled force signal was low-pass filtered, with a 10-Hz cutoff (zero-phase lag, fourth-order Butterworth filter). A torque (N·m) signal was subsequently derived off-line by multiplying the force (N) signal from the load cell by the lever arm (m) for each participant (35). The lever arm was measured as the distance from the greater trochanter to the heel (positioned over the load cell), and was measured once prior to the strength assessment testing. The passive baseline torque value was considered the limb weight and subtracted from the signal so that the new baseline value was 0 N·m. All subsequent analyses were conducted on the scaled, filtered, and gravity-corrected torque signal.

Absolute isometric MVC PT (N·m) was determined as the highest mean 500-millisecond epoch during the entire 3–4 second MVC plateau (Figure 2). The absolute PT was also divided by the participants' body weight to provide a body mass normalized (relative) expression of maximal strength (PTnorm; N·m·kg^{-1}). Absolute RTD (N·m·second^{-1}) was calculated as the linear slope of the torque-time curve (Δtorque/Δtime) at time intervals of 0–50 (RTD50) and 0–200 (RTD200) milliseconds (Figure 2) (51). These time intervals were chosen for analysis because they represent rapid torque characteristics in the early (0–50 ms) and late (0–200 ms) phases of muscle contraction (33), and have been previously shown to effectively differentiate among strength-related performances (49). The absolute torque-time curve was also subsequently normalized to PT from which relative RTD values (%MVC·second^{-1}) were calculated from the normalized torque-time curve for the same 0–50 (RTD50norm) and 0–200 (RTD200norm) millisecond epochs used to calculate absolute RTD. For each MVC, the onset of contraction was determined as the point when the torque signal reached a threshold of 4 N·m (34). Of the 2 MVCs performed, the MVC with the higher PT was selected for analysis, unless the MVC with the lower PT was (1) within 10 N·m of the MVC with the high PT and (2) the RTD values for this lower PT MVC were greater (>20 N·m·second^{-1}) than the RTD values for the high PT MVC, in which case, the MVC with the lower PT was selected instead. These selection procedures helped to ensure that the MVC with the best overall PT and RTD values was chosen for analysis.

Test-retest reliability for these procedures from our laboratory was examined during manual isometric hip extension MVCs from 10 participants measured 48–72 hours apart. For all the maximal and rapid isometric torque variables reported in this study, the ICCs and *SEM* values expressed as a percentage of the mean ranged from 0.64–0.92 and 11.8–21.3%, respectively.

Statistical Analyses

Independent samples *t*-tests were used to analyze differences in demographic and physical activity (aerobic and resistance exercise) characteristics, absolute and normalized PT and RTD variables, and OSI between the young and old females. Type I error rates (p) and effect sizes were reported for each between-group comparison. Effect size statistics were calculated by dividing the absolute value of the difference in the performance variable between groups by the pooled *SD* (16). Pearson product-moment correlation

TABLE 1. Mean (*SD*), 95% CI, and effect size values for absolute and normalized PT and RTD at time intervals of 0–50 and 0–200 milliseconds and OSI.*

	Young ($n = 11$)	Old ($n = 11$)	Effect size
PT (N·m)	94.89 (23.95)	70.28 (31.02)†	0.83
95% CI	78.80–110.98	49.44–91.11	
PTnorm ($N \cdot m \cdot kg^{-1}$)	1.34 (0.50)	1.03 (0.37)	0.67
95% CI	1.00–1.67	0.78–1.28	
RTD50 ($N \cdot m \cdot s^{-1}$)	364.14 (121.74)	254.30 (105.87)†	0.88
95% CI	282.36–445.93	183.18–325.43	
RTD50norm ($\%MVC \cdot s^{-1}$)	389.18 (155.66)	380.62 (145.04)	0.06
95% CI	284.61–493.75	283.18–478.06	
RTD200 ($N \cdot m \cdot s^{-1}$)	274.29 (82.17)	180.16 (69.00)†	1.07
95% CI	219.09–329.49	133.80–226.51	
RTD200norm ($\%MVC \cdot s^{-1}$)	283.75 (58.72)	253.33 (86.63)	0.41
95% CI	244.30–323.20	195.13–311.53	
OSI	0.48 (0.16)	0.69 (0.19)†	1.05
95% CI	0.37–0.59	0.57–0.82	

*CI = confidence interval; PT = peak torque; RTD = rate of torque development; OSI = overall stability index; MVC = maximal voluntary contraction.

†Indicates significantly higher OSI values and lower absolute PT and RTD at RTD50 and RTD200 for the old compared with the young females ($p \le 0.050$).

coefficients (r) were calculated separately for the young and old females to examine the relationships between PT, RTD50, RTD200, and OSI. Statistical analyses were performed using IBM SPSS Statistics v. 21.0 (SPSS, Inc., Chicago, IL, USA). All p values were rounded to 3 decimal places, and statistical significance was declared if the rounded p value was less than or equal to 0.050.

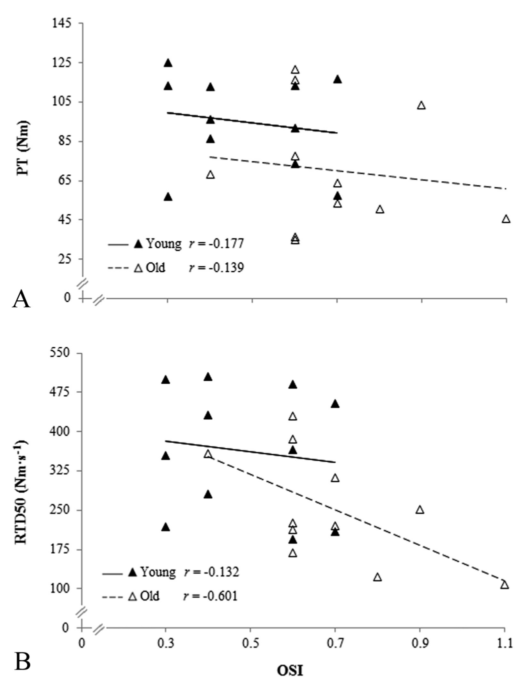

Figure 3. Relationships between overall stability index (OSI) and peak torque (PT) (A) and rate of torque development (RTD) at RTD50 (B) for the young and old females.

RESULTS

There were no differences between the young and old females for body mass ($p = 0.289$), height ($p = 0.329$), BMI ($p = 0.443$), or volume of aerobic ($p = 0.687$) and resistance ($p = 0.077$) exercise. Table 1 shows the means, *SD*s, confidence intervals (CIs), and effect sizes for absolute and normalized PT and RTD variables and OSI. The old females exhibited higher OSI values ($p = 0.011$, effect size = 1.05) and lower absolute PT ($p = 0.050$, effect size = 0.83) and RTD at RTD50 ($p = 0.035$, effect size = 0.88) and RTD200 ($p = 0.009$, effect size = 1.07) compared with the young females. There were no differences between the young and old females for PTnorm ($p = 0.113$, effect size = 0.67) or relative RTD at RTD50norm ($p = 0.895$, effect size = 0.06) and RTD200norm ($p = 0.347$, effect size = 0.41). Significant positive relationships were observed in the young and the old females between PT and RTD200 ($r = 0.684$ and 0.641, respectively; $p = 0.020$ and 0.034) but not between PT and RTD50 ($r = 0.196$ and 0.510; $p = 0.564$ and 0.109). A significant negative relationship was also observed between OSI and RTD50 in the older females ($r = -0.601$; $p = 0.050$; Figure 3) but not in the younger females ($r = -0.132$; $p = 0.698$; Figure 3). No relationships were observed in the young and older females between OSI and PT ($r = -0.177$ and -0.139; $p = 0.602$ and 0.683; Figure 3) or OSI and RTD200 ($r = 0.106$ and 0.103; $p = 0.755$ and 0.764).

Discussion

The primary findings of this study revealed that absolute maximal and rapid torque characteristics (i.e., PT, RTD50, and RTD200) were significantly lower in the old compared with the young females, whereas these differences were not present for the relative maximal or rapid torque characteristics (i.e., PTnorm, RTD50norm, and RTD200norm; Table 1). The old females also exhibited higher OSI values than the younger females (Table 1). In addition, a significant negative relationship was observed between OSI and RTD50 for the older females; however, no such relationship was observed for the younger females nor were there any relationships between OSI and PT or RTD200 for either age group (Figure 3).

Previous studies examining age-related reductions in absolute maximal and rapid torque capabilities have reported a wide disparity in declines for different muscles between young and old adults. For example, previous investigations comparing these populations have reported 29–46% decreases in maximal strength and 36–68% decreases in rapid strength for the leg extensor (12,19,24,27,49) and flexor (49) muscles, whereas other studies examining the dorsiflexors (4,21,38) and plantar flexors (4,46,48) have reported 14–33% and 25–50% decreases in maximal and rapid strength, respectively. In the present study, PT and RTD50 for the hip extensor muscles were 26 and 30% lower in the old compared with the younger females. Although these findings are within the ranges previously reported in old vs. younger females for the dorsiflexors (38), they are slightly lower than those of Ditroilo et al. (12) and Thelen et al. (46) who reported 32–36 and 36–42% decreases in maximal and rapid torque production, respectively, between young and old females for the leg extensors and plantar flexors. These modest discrepancies in strength reductions may be attributed to differences in the RTD time intervals examined, age-range variations, and/or age-associated differences in the torques and powers produced by the musculature at the hip, knee, and ankle joints during functionally related tasks (4,11,19,42,49). For example, Savelberg et al. (42) demonstrated that aging causes a redistribution of joint torques and powers during walking, such that older adults generate greater power at the posterior hip and less power at the anterior knee and posterior ankle than younger adults. Thus, it is possible that the habitual performance of walking-related tasks in the elderly while producing greater torque and power at the hip may help to attenuate the age-associated declines in maximal and rapid torque characteristics of the hip extensor muscles to a greater degree than those of the leg extensors and plantar flexors. Although further research is still needed to test these hypotheses regarding the effects of the relationships between functional performances, muscle groups, and age-related strength declines, the present findings of greater differences and effect sizes between age groups for absolute RTD (effect sizes = 0.88–1.07) than PT (effect size = 0.83) in the hip extensors are in agreement with previous studies (21,24,49) that have suggested that the age-related reductions in absolute rapid torque production may be more pronounced than the age-related declines in maximal strength.

Although a number of studies have examined age-related changes in knee and ankle muscle strength, relatively few studies have documented age-related changes in hip extensor muscle strength, and more specifically, the age-related changes in RTD. The hip extensors, which include the hamstrings, have been identified as being important contributors to many functional-related movement tasks, including walking (8), running (10), jumping (50), and balance (34). Because these tasks may be important for activities of daily living and sustaining functional independence (49), it is possible that an age-associated reduction in rapid torque production of the hip extensors, as has previously been reported for other muscle groups, may be a significant contributor to the functional decline that is often observed in older individuals (46). A unique finding of this study was that RTD50 and RTD200 of the hip extensors were lower in the old compared with the younger females. These age-related declines, although slightly lower than those previously reported in other muscles (i.e., leg extensors, plantar flexors), are still considered a large and practically important effect (effect size ≥ 0.88) and could as a result of the hip extensors' contribution to important locomotor-related tasks, explain some of the early deficits in functional performances that are often regarded as a consequence of aging (49). As such, hip extensor strengthening programs with an emphasis on explosive power training may be warranted as a preventative measure for older adults who are at risk for abrupt functional decline. Future studies are needed to explore the efficacy and effectiveness of training programs aimed to improve hip extensor muscle performance for the maintenance and/or restoration of locomotor function and independence in the elderly.

Despite significant age-related differences for absolute PT and RTD values, no age-related differences were observed for relative PT or RTD. These findings are consistent with those of previous studies, which demonstrated a lack of normalized PT and/or RTD differences in the dorsiflexors (9) and the leg extensors and flexors (49) between healthy, young and older adults. Alternatively, however, other authors have shown in older males and females that relative rapid strength measurements of the leg extensors (22,27), dorsiflexors (21), and plantar flexors (48) were significantly lower than those of younger populations. Nevertheless, it should be noted that these authors examined elderly individuals who were older and/or participated in a lower volume of physical activity, which may have influenced the results and potentially contributed to the greater age-related declines in relative rapid strength that were found in their studies compared with the present study. For example, these studies examined lower active (3.7 $hours \cdot week^{-1}$) (27) and/or older populations with a mean age of ~69–76 years (21,27,48); however, the present study examined higher active (6.5 hours$\cdot$week^{-1}), and somewhat younger (mean age = 67 years) elderly females and found no differences in PTnorm, RTD50norm, or RTD200norm between age groups. This may suggest lesser age-related sensitivity of relative PT and RTD values, and/or different age-related physiological mechanisms between relative and absolute RTD (48). For example, it has been hypothesized that in the absence of significant age-related differences in relative RTD which reflect more qualitative physiological characteristics (i.e., fiber type motor unit and discharge firing rates, tendon stiffness, pennation angle) (1,48), absolute RTD differences between age groups may be the result of lower maximal strength (49). Support for this hypothesis is highlighted in the present findings by the significant positive relationships observed between PT and RTD200 in the young ($r = 0.684$) and older ($r = 0.641$) females. Moreover, given the significant relationships reported by previous studies between muscle mass, strength, and RTD (23,41), it is also possible that the lower muscle size values typically observed in older compared with younger adults, may have played a significant role in the lower PT and absolute RTD values observed for the older females in the present study. However, given the scope of this study, and the limited data available regarding these variables and findings, it is not presently feasible to ascertain the underlying mechanisms resulting in the lower maximal and rapid torque characteristics for the old compared with the young females. Thus, future research involving more invasive measures (i.e., ultrasound imaging, electromyography, etc.) specific to the hip extensor muscles may be necessary to elucidate the mechanisms responsible for influencing the strength-related differences (or similarities) displayed between groups of individuals with varying ages.

The higher falls risk OSI values observed for the older females in the present study (Table 1) indicated that these individuals were less able to maintain the balance platform in a level position, placing them at a greater risk for falls than the younger females. Although the reasons for these age-related disparities are uncertain, it is possible, given the older females' substantially lower RTD values, that the decreased stability and greater falls risk were at least partially influenced by the rapid torque characteristics of the hip extensor muscles in the old compared with the younger females. Previous authors have suggested that the inability to produce torque rapidly is a limiting factor in the performances of balance-related tasks (5,45) and that lower RTD in females, and in particular older females who are over the age of 60, may lead to a decreased ability to recover from a loss in balance to avoid a fall (5,31,34). Our findings would support these hypotheses given the significant negative relationship ($r = -0.601$) observed between early rapid torque production (RTD50) and OSI values in the older females; however, it should be noted that no such relationship was observed in the younger females ($r = -0.132$). Similarly, Izquierdo et al. (19) demonstrated a significant relationship in older ($r = -0.530$) but not younger ($r = -0.270$) males between dynamic balance control and peak RFD of the leg extensor muscles. Thus, taken together, these findings provide support that peak and/or early explosive strength characteristics of the lower extremity musculature may play an important role in dynamic balance and falls risk, especially in older populations. However, it is noteworthy that the present findings did not support the relationship between maximal strength (PT) nor later rapid torque (RTD200) characteristics and OSI scores in this active older female population. Because maximal and later rapid torque production involve relatively long torque development durations of $\geq$200 milliseconds (3,52), it is possible that these strength characteristics, given their low response time-related functional relevance with fast (i.e., $\leq$100–200 ms) and forceful movement tasks (e.g., balance recovery) (37,47), may be less effective measures for predicting dynamic balance and falls risk in healthy older adults.

A potential limitation of this study was the low sample size, which may have influenced our results. For example, despite the possibility of low functional relevance between maximal and later rapid strength and dynamic balance, it is also possible because of the low number of participants in this study that the lack of significant relationships between OSI and PT and RTD200 may be due to inadequate statistical power. Nevertheless, these findings highlight the potential of an effective strength-based functional screening tool in young and older adults; however, we do acknowledge that future research involving larger sample sizes and additional muscle groups (i.e., hip flexors) and sway parameters (to different directions) are warranted to provide a more thorough evaluation of the relationships between maximal and rapid strength of the hip muscles and balance-related performance. In addition, it should be noted that the BMI values of 4 younger participants were over 30 kg$\cdot$m^{-2}, which would classify them as obese. However, given the fact that BMI does not differentiate between fat and fat-free mass (39), it is possible that the higher BMI values observed for these participants was not because they were obese but rather because they had a greater amount of lean muscle tissue. Nevertheless, because mean BMI was not significantly different between age groups, it is unlikely these values had a significant impact on the present findings. However, caution should still be advised to those attempting to generalize these findings to other populations (with lower BMIs).

Practical Applications

In summary, our findings indicated lower absolute maximal and rapid torque capacities of the hip extensor muscles in old compared with younger females. These findings were largely similar (although unsubstantially lower compared with the leg extensor and plantar flexor muscles) with those of previous studies examining other muscle groups and support the notion that aging may have an adverse effect on maximal and explosive strength, even in healthy, physically active older adults. Relative PT and RTD values were similar between the young and older females, suggesting that the age-related changes in absolute RTD were most likely the result of quantitative factors such as differences in maximal strength and/or muscle size. In addition, the older females exhibited higher OSI values than the younger females, which suggests that aging may also have a deleterious effect on dynamic balance and falls risk. Moreover, given the negative relationship between OSI and early rapid torque production in the older females and the lack of such a relationship in the younger females, the present findings suggest that these age-related declines in explosive strength may be an important characteristic relevant to dynamic balance scores (that are indicative of falls risk), especially in older populations. Physical therapists, strength and conditioning specialists, and other practitioners may potentially use these findings as performance evaluation tools to help in identifying older females with lower RTD and inferior postural balance, which may possibly be an indicator of overall functional decline. In addition, these findings also highlight the need to implement training programs, which focus on the hip extensor musculature in older females, especially for those who are experiencing balance problems and are at an increased risk for falls (20). Previous studies (13,40,43) have reported that certain training exercises (i.e., leg press, seated leg extension, prone leg curl, etc.) that are performed at a high velocity of movement can be used to help improve muscle power characteristics of the hip extensors and other muscle groups in healthy, physically active older populations. Therefore, it is possible that incorporating these types of exercises in a resistance training program may also be used to help improve hip extension RTD production, which could be beneficial for improving a multitude of other functional performance abilities (i.e., maximal walking speed, chair-rise performances) (33,44), as well as being a primary strategy for reducing the potential risk of falls and other balance-related injuries that are common debilitating occurrences in elderly adults (5,37).

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