Relationships Between Muscle Characteristics and Step Outcomes in Young and Old Adults

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RELATIONSHIPS BETWEEN MUSCLE CHARACTERISTICS AND STEP OUTCOMES IN YOUNG AND OLD ADULTS

by

Kareem Abubukker

A plan B research project submitted in partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE

in

Kinesiology

Approved:

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Logan, Utah

2023
Abstract

**Background:** Falls are a primary cause of mortality and morbidity in older adults. In an effort to assess falls, a number of studies have measured neurological, biomechanical, and neuromuscular function in relation to fall risk. Despite efforts, falls continue to affect the older adult population leading to subsequent impaired mobility and function. Multiple factors contribute to fall risk among older adults, however, a factor that has shown a consistent relationship with the prevalence of future falls is reduced muscle characteristics. Moreover, the ability to rapidly accelerate a limb, as captured by rate of power development (RPD), rate of velocity development (RVD), and peak power (PP) could have an important role in balance recovery. When stepping to avoid a fall, the ability to move a limb is critical, therefore, and step time provides insight into these relationships. Our overarching purpose was to determine how time to peak values, not solely peak values, were associated with reactive balance performance.

**Research Question:** Will RPD, RVD, and PP have a strong, positive relationship with maximal lean angle as well as a strong, negative relationship with step time following a temporally unpredictable perturbation? We hypothesized that older adults would have a strong, positive relationships among RPD, RVD, PP and maximal lean angle as well as strong, negative relationships with step time when compared to young adults.

**Methods:** Females and males between 18 and 35 years old, and those between 55 and 85 years old were recruited to complete a cross-sectional design. Subjects reported for two visits to the Neuromuscular Research Laboratory and the Movement Analysis Laboratory. After a dynamic warm-up, subjects performed the stretches by alternating limbs and performed experimental
strength testing and balance (rapid step) protocols. The strength testing protocol involved three maximal vertical jumps while standing on a jump mat and a seated isometric, isokinetic, and isotonic dynamometer test was used to assess leg extension/flexion and hip extension/flexion in which peak torque (PT), RPD, RVD, and PP were measured. The rapid step protocol involved temporally unpredictable perturbations, in which each trial began at a lean angle of 10° and progressed by 5° increments with successful completion. Trials consisted of three attempts to regain balance following a postural perturbation, and two successful completions were required. Outcome measures maximal lean angle and step time were expected to have a strong, positive correlation with, RPD, RVD muscle characteristics.

**Results:** A total of 35 participants completed the two visits including young (n = 26) and older adults (n = 9). Young adults did have significant associations between isometric, knee extension PT (e.g., step time r = .407, p = .024), older adults did have a significant, positive association between maximal lean angle and PT (r = .607, p = .042). Among young adults, no significant associations were present between step outcomes (maximal lean angle and step time) and PP, RVD, or RPD variables. However, among older adults, maximal lean angle, and PP (r = .640, p = .032), RVD (r = .608, p = .041), and RPD (r = .751, p = .010) all reported significant, positive associations.

**Significance:** Our results suggest older adults’ muscle characteristics (e.g., PP, PT, RVD, RPD) have strong, positive relationships with the achieved maximal lean angle. While young adults did have significant associations between isometric, knee extension PT (e.g., step time r = .407, p = .024). When stepping to avoid a fall, the ability to rapidly move a limb is critical and time-
dependent muscle capacities (e.g., RPD, RVD, and PP) are important determinants of limb movement.
Introduction

Falls are a primary cause of mortality and morbidity in older adults \(^1\). In an effort to assess falls, a number of studies have measured neurological, biomechanical, and neuromuscular function in relation to fall risk \(^2\)–\(^4\). Despite efforts, falls continue to affect the older adult population leading to subsequent impaired mobility and function \(^5\). Multiple factors contribute to fall risk, however, one factor that has shown an intriguing relationship with the prevalence of future falls is reduced muscle function characteristics (e.g., grip strength) \(^6\).

Indeed, various measures of muscle function and balance performance have proved indicative of fall risk \(^5\)–\(^12\). Specifically, greater leg strength, greater ankle torque \(^7\), and lower-limb muscular strength \(^8\) are all linked to better performance on balance tests, which are associated with decreased falls and fall related injuries \(^9\)–\(^12\). Moreover, the ability to rapidly accelerate a limb is important in balance recovery. As a critical strategy used when recapturing a falling center of mass, step reactions are used \(^13\). Rapid muscular strength capacities have been shown to be inversely related \((r = -.60)\) to dynamic stability in female, older adults \(^14\). When compared to young adults, Thelen et al. 2000 found that older adults do not show substantial differences in muscular activation (i.e., electromyography) onsets during balance recovery, suggesting that age-related differences of balance recovery abilities are likely attributable to muscular characteristics following the initiation of a forward-fall recovery. In comparison, previous work has primarily focused on the torque or force (i.e., isovelocity) component of a muscle action, with little research on velocity or power \(^15\). These torque measurements constrain velocity and derive results from torque production, despite contraction velocity being a critical component of muscle function \(^16\). Van Driessche et al. 2018 suggested that power and velocity measurements may be indicative of improved functional performance.
Muscle characteristics influential to torque, power, and velocity are muscle mass, fiber type composition, and fiber arrangement. Aging is detrimental to each of these muscle-related characteristics and may explain part of the association between muscular strength and balance performance. Of particular importance, aging is associated with a shift from fast-to-slow-twitch muscle fibers. The shift from fast-twitch muscle fibers reduces the ability to generate a high rate of power development (RPD) or power output at the joints. Moreover, current research has investigated fall-risk and rapid muscle characteristics (rate of torque development (RTD) and/or power variables) in order to elucidate the relationship among age, fall-risk, and relevant muscle function characteristics. For example, age-related declines are greater in rate of power development (RPD), rather than peak torque (PT) and peak power (PP) variables. In addition, a decline in rapid power development is apparent by as early as age forty, indicating these rapid power capacities may be sensitive age-related indicators.

When stepping to avoid a fall, the ability to move a limb is critical, with similar muscular onset necessary for young and old adults. Both high PT (e.g., maximum muscular strength) and time-dependent muscular strength capacities (e.g., RPD, and rate of velocity development (RVD) are important determinants of limb movement abilities. Power is the rate of performing work (work/time) and thus incorporates both the torque and velocity components of a muscle-induced movement. While RPD is a rather novel variable which accounts for the earlier phase of the power development curve, RVD is measure of acceleration at the onset of muscular contraction.

Moreover, compensatory balance responses to temporally unpredictable perturbations are approximately twice as fast as voluntary reactions, thus specific force generation demands are amplified in a postural context. Indeed, generating a single, well-placed step with sufficient
speed is one hallmark of an effective balance recovery response. Aging compromises stepping ability during balance performance, and slower step performance in older adults is associated with increased falls and balance impairment. Due the importance of one’s ability to generate force quickly to move a limb in the event of a fall, we anticipate the step time of a single well-placed step would have a strong, negative correlation with our muscle characteristics. It remains to be determined; however, which muscle characteristics are the most sensitive predictors of stepping ability and balance recovery. Understanding which muscle characteristics are most relevant for stepping performance in older adults is an important and necessary step to advance the mechanistic understanding of physiological factors and enhance the development of fall mitigation interventions.

During a fall, standing balance strategies are inadequate, and measurements following a temporally unpredictable perturbations are needed. Thelen et al. 2000 used a lean and release mechanism to force an unanticipated perturbation, and Ochi et al. 2019 found a strong, positive correlation between maximum recoverable lean angle with RTD and PT. To the best of our knowledge, a lean and release paradigm has not been utilized to assess these power and velocity responses among older adults. Therefore, our purpose was to determine if muscle characteristics time to peak values are associated with step outcomes following temporally unpredictable perturbations. We hypothesized that older adults would have strong, positive relationships among RPD, RVD, and maximal lean angle as well as strong, negative relationships with step time when compared to young adults. If such relationships are present, it may offer support that the time to peak values, not solely peak values, should be used as an assessment of individual predicted reactive balance performance.
Methods

Subjects

Females and males between 18 and 35 and 55 and 85 years old were recruited through flyers and oral communication. Individuals completed a health history questionnaire and were excluded if they had any lower body injuries within the previous 1-year period or any known neuromuscular diseases (e.g., Multiple Sclerosis). Moreover, individuals were required to be independently ambulatory, such that they do not require the use of assistive walking devices (e.g., cane). All subjects read and signed a written informed consent form. The study was approved by the Utah State University Institutional Review Board (No. 10156).

Experimental Procedures

The study used a cross-sectional design and matched young and old groups for gender. Subjects reported on two occasions to the Neuromuscular Research Laboratory and the Movement Analysis Laboratory, located in Utah State University’s Sorenson Legacy Foundation Center for Clinical Excellence (visit 1 = familiarization and debriefing session, visit 2 = testing). During the first visit, subjects read over the informed consent document, as well as answered a health and physical activity questionnaire. Then the subjects had their height and weight measured in a private room. Following this, a five-minute warm-up on a cycle ergometer was performed at a self-selected pace and at a constant 50 watts, followed by a lower-body dynamic warm-up involving five repetitions of a quadricep stretch, a gluteal stretch, an adductor stretch, and a hamstring stretch. Subjects performed the stretches by alternating limbs and a table was used for hand support as needed with older adults. After the warmup, on the first visit, practice trials of familiarization testing were completed. The second visit of testing consisted of the
warm-up as previously described followed by the experimental strength testing and balance (rapid step) protocols (Figure 1).

**Figure 1.** Experimental Procedures.

*Muscle function testing*

Subjects performed three maximal vertical jumps while standing on a jump mat (Just Jump Technologies, Huntsville, AL, USA), with their shoes on. Jumps were performed individually, with hands placed on their hips and were given 60 s of rest between jumps. Following vertical jump testing, subjects performed a maximal hand grip strength tests using their dominant hand. Subjects were asked to stand and hold their arm at a 90° angle and grip as hard as possible. After, subjects were seated on a dynamometer (Biodex Medical Systems, New
York, NY, USA) and secured to the seat with restraining straps placed over their right hip and thigh per manufacturer guidelines. The right lower limb was fixed to a padded lever arm approximately five centimeters above the lateral malleolus. Strength testing began with three isokinetic knee-extension maximal voluntary contractions (MVC)s at 240°/s. Subjects then performed three maximal isometric knee extension MVCs at 60° (0° horizontal), separated by three minutes of rest between repetitions.

Subjects then performed three individual maximum velocity knee-extension repetitions at 25% of their maximum isometric torque from the familiarization trial, followed by three individual maximal unloaded repetitions with the load was set at 0.5 ft·lb per the lowest setting of the Biodex, as published previously. Following this, subjects performed three individual isokinetic hip flexion MVCs at 240°/s. This was then followed by three unloaded (0.5 ft·lb) maximum hip flexion repetitions. The hip flexion test was completed in a standing position as shown in Figure 2. A stable support (e.g., Biodex dynamometer) was provided and approximately two minutes of rest were allotted between each of the sets. The outcome measures included PT, RPD, and RVD as representing maximal and rapid muscle characteristics.

Figure 2. Standing hip flexion test.
Rapid Step testing

As shown in Figure 3, a custom-made ‘lean and release’ cable system was used to impose a temporally unanticipated perturbation. While some aspects of the postural perturbation were predictable, such as the direction and amplitude, the exact time of the cable release was unpredictable. A safety cable was attached to the safety harness and used to catch the subject if they failed to make a successful step. Another support cable was attached from the back of the harness to a wall supported magnet. The magnet was used as a posterior support, to place the subject in a forward position. Gaze was standardized by having the subject fixate in the general area of the tape strip, which was their step target and set at 35% of their height. Trials were initiated by a verbal cue and followed with a ‘start signal’ button of signal software, with randomized timing options. Wireless differential surface electrode electromyography footswitches (Delsys Inc., Boston, MA, USA) were used to measure step characteristics. Two electrodes were taped on the underside of the subject’s right shoe. One electrode was taped
approximately under the third meta-tarsal, with the second load cell taped two centimeters behind. The time between step-foot lift off and touch down was manually calculated with Signal Software and a Cambridge Electronic device (Power 1401, Cambridge Electronic Design, Cambridge, UK) and used to analyze step time.

The experimental design had subjects produce a rapid step response to a temporally unanticipated perturbation. On visit one, subjects were familiarized and trained on the task, and performed temporally unanticipated perturbation trials. When subjects would lean standing forward position for the start of each trial, they were instructed to step only with their right leg to a strip of tape marked at 35% of their height (cm) which allowed for a safe and comfortable lean angle for all participants. Each trial began at a lean angle of 10° (measured as the angle between the floor and shank using a manual goniometer) and progressed by 5° increments with successful completion. Trials consisted of three attempts to regain balance following a postural perturbation, and two successful completions were required to record the maximal lean angle in degrees. A successful completion was defined as a single rapid step, held for approximately two seconds, with the right leg while using no hand support.

**Figure 3.** Custom ‘lean & release’ system. Subjects were put in a safety harness attached to an able preventing a fall. Another cable attachment allowed the subject to lean forward, and an unanticipated cable tension release forced a forward step. Footswitches were taped to the underside of the subject’s shoes to measure time between initial step lift off and step touch down.
This allowed us to quantify subjects’ ability to recover from a fall upon being thrown off balance and determine the effectiveness of an individual fall recovery response in relation to muscle characteristics.

**Data Analysis**

Descriptive statistics were conducted overall as well as stratified by group. Summary values including mean ± standard deviation or number (percentage). Pearson product-moment correlation coefficients were used to measure the strength of the relationship between step outcomes (e.g., maximal lean angle, and step time) and muscle characteristics (e.g., vertical jump performance, PT, RPD, RVD, and PP). Alpha was set at a priori ≤ 0.05.

**Results**

Table 1 presents the demographic data of participants. A total of 35 participants completed the two visit assessments. For older adults (n = 9), there was a significant, positive association between weight (kg) and height (cm), r = .636, p = .033. Mean ± standard deviation is presented for maximal lean angle, step time, vertical jump performance, and dominant hand grip strength.

<table>
<thead>
<tr>
<th>Table 1. Participant demographics characteristics</th>
<th>Young</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>age, years</td>
<td>22.79 ± 2.9</td>
<td>67.33 ± 8.1</td>
</tr>
<tr>
<td>sex, Female (n, %)</td>
<td>24, 54%</td>
<td>9, 44%</td>
</tr>
<tr>
<td>height, cm</td>
<td>169.52 ± 9.69</td>
<td>170.33 ± 8.83</td>
</tr>
<tr>
<td>weight, kg</td>
<td>70.67 ± 16.44</td>
<td>72.36 ± 11.92</td>
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</table>
Table 2 outlines the Pearson product-moment coefficient associations between two step outcomes (e.g., maximal lean angle and step time) and muscle characteristics (e.g., vertical jump performance, PT, RPD, RVD, and PP). There were no significant associations between vertical jump performance for young (maximal lean angle $r = .329, \ p = .058$; step time $r = .122, \ p = .285$), or older adults (maximal lean angle $r = .514, \ p = .078$; step time $r = -.491, \ p = .090$). However, the young adults did have significant associations between isometric, knee extension PT and step time ($r = .407, \ p = .024$), and the older adults had a significant, positive association between maximal lean angle and PT ($r = .607, \ p = .042$). Among young adults, no significant associations were present between step outcomes (maximal lean angle and step time) and PPP, RVD, or RPD variables. However, among older adults, maximal lean angle and PP ($r = .640, \ p = .032$), RVD ($r = .608, \ p = .041$), and RPD ($r = .751, \ p = .010$) reported significant, positive associations.

Table 2. Pearson product-moment coefficient ($r$) associations between maximal lean angle, step time and muscle characteristics including vertical jump, isometric knee extension PT, and isotonic rate of power development (quads 25% isotonic rate of velocity development, and isotonic rate of power development.

<table>
<thead>
<tr>
<th></th>
<th>maximum lean angle</th>
<th>step time</th>
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<tbody>
<tr>
<td>Young</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertical jump</td>
<td>$r = .329, \ p = .058$</td>
<td>$r = .122, \ p = .285$</td>
</tr>
<tr>
<td>isometric, knee extension PT 500</td>
<td>$r = .191, \ p = .185$</td>
<td>$r = .407, \ p = .024^*$</td>
</tr>
<tr>
<td>PP (quads isokinetic 240°/s)</td>
<td>$r = .199, \ p = .176$</td>
<td>$r = .145, \ p = .249$</td>
</tr>
</tbody>
</table>
Discussion

Here we sought to determine if time to peak muscle characteristics had significant associations performance on a balance recovery stepping task (e.g., maximal lean angle, step time) following temporally unpredictable perturbations. We hypothesized that older adults would have a strong, positive relationships among RPD, RVD, PP and maximal lean angle, as well as strong, negative relationships with RPD, RVD, PP and step time when compared to young adults. Our results indicate that the hypothesis was partially supported. Among young adults, there were significant associations between isometric, knee extension PT, and step time ($r = .407$, $p = .024$). However, older adults did have significant, positive associations between maximal lean angle, and PP, RVD, RPD measures. Review of peak values such as PT and PP also indicated that a strong, positive association with maximal lean angle for older adults. Furthermore, although step time and muscle characteristics indicated a negative association, these non-significant.

Our results provide offer support that among older adults’ muscle characteristics (e.g., PP, PT, RVD, RPD) have strong, positive relationships with maximal lean angle. When stepping
to avoid a fall, the ability to rapidly move a limb is critical. Muscle characteristics such as PT as well as time-dependent muscle capacities (e.g., RPD, RVD, and PP) are important determinants of limb movement. This finding aligns with Palmer et al. 2016 that found that time to peak values were inversely related (r = -.6) to dynamic stability in older, female adults. In a reactive balance context, the maximal lean angle achieved will influence muscle characteristic relationships. While our results indicate that a maximal lean angle of 15.56 ± 8.5° was achieved among older adults, past work had reported both similar and contrasting maximal lean angles. For example, Carbonneau et al. 2014 reported similar maximal lean angles for older adults (13.2 ± 8.7°), but Thelen et al. 2000 reported a maximal lean angle of 23.5 ± 2.6° for older adults.

Muscle characteristics did not have significant associations with maximal lean angle among young adults. In comparison, Ochi et al. 2019 found that RTD for both hip and knee flexion could predict maximal recoverable lean angle in young adults. Several factors could influence the differences observed in time to peak value outcomes including sample size (54 versus 24 young adults), different peak value outcomes (RTD versus RPD, RVD, PP), subject age (young versus old), and target joint and action (knee flexion and hip extension versus knee extension), and maximal lean angle (32.4 ± 5.1° versus 24.17 ± 6.9°). While initial procedures were similar to obtain maximal lean angle, after two failed attempts to recover balance, the forward angle was reduced by 2° until balance was successfully recovered twice influencing some of the variation in angles (Ochi et al., 2019).

Step time had insignificant, weak, negative associations with time to peak muscle characteristics, with our results indicating a slower step time for young (0.27 ± 0.35 ms) compared to older adults (0.22 ± 0.04 ms). Our protocol design may have inadvertently influenced these results with our design utilizing a fixed stepping target. Moreover, subjects were
instructed to always step forward with their right limb, regardless of their dominant or preferred stepping limb. When comparing results of young and older adults, Carbonneau et al. 2014 suggests that aging process slows down step velocity, which may influence the step time outcome. Thelen et al. 2000 assessed step length and found that compared to young adults, older adults step length was diminished by 22%. The faster step time found with older adults may have led to shorter step lengths. These shorter step lengths among older adults may be influenced by co-contraction, age-associated increases influenced by increased joint stiffness 33. Specifically, ankle stiffness has been associated with older adults who fall compared to non-fallers (p = .018) 34.

**Limitations**

Our study was not without limitations. Unfortunately, as data collection was occurring, the COVID-19 pandemic halted data collection for this study. While the young adult population included 24 subjects, only nine older adults were recruited limiting the ability to make direct comparisons across groups. In addition, although the inverse association was present between step time and muscle characteristics, these associations did not result in significant relationships. It is likely that although the maximal lean angle was increased during the reactive balance testing, it may not have influenced step speed enough to result in a difference in step time. Moreover, the step location was a fixed target, which may have influenced stepping performance and may limit translation to real-world translation for balance recovery. Other factors such as footwear choice could influence stepping ability, especially in the mediolateral direction. For example, a small increase in footwear sole may impact older adults may improve lateral stability 35. Indeed, the impact of footwear may be most beneficial for older adults, although a comparison
of young adults barefoot and with shoes found that shoes did not impact anterior posterior
direction, footwear choice in the mediolateral direction exhibited greater anticipatory
perturbation adjustment size and velocity \(^ {36}\).

**Future Directions**

In the near future, expanding upon the current older adult sample (\(n = 20\)), would provide
an opportunity for robust group comparisons in muscle and stepping characteristics. Moreover,
several studies have suggested that perturbation training may improve stepping, with important
implications for fall prevention \(^ {37-40}\)

**Conclusion**

Our results suggest older adults’ muscle characteristics (e.g., PP, PT, RVD, RPD) have
strong, positive relationships with the achieved maximal lean angle. When stepping to avoid a
fall, the ability to rapidly move a limb is critical and time-dependent muscle capacities (e.g.,
RPD, RVD, and PP) are important determinants of limb movement. Relationships between
muscle characteristics and step time were weak, negative insignificant relationships for both
young and older adults for time to peak values (e.g., PP, RVD, and RPD) suggesting that,
perhaps step time is not related to time-dependent muscle capacities.
References


