

Age-related differences in vertical jump height and handgrip strength measurements

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Purpose: This study aimed to examine the effects of age on vertical jump height and handgrip strength measurements in women. A secondary aim was to investigate the correlations between vertical jump height and handgrip strength. *Methods:* Twenty young (21.5 ± 2.8 years) and twenty older (67.0 ± 5.5 years) healthy women participated in this study. Handgrip contractions were used to assess strength measurements of peak force and rate of force development at different time intervals. Vertical jumps were performed on a jump mat. The jump mat measured vertical jump height based on flight time. *Results:* The older women had lower vertical jump height ($P < 0.001$) and handgrip peak force ($P = 0.028$) and rate of force development values ($P = 0.003$ – 0.016) than the younger women. A larger difference was observed between the groups for vertical jump height (41%) than handgrip peak force and rate of force development (12–17%). Of all the strength measurements, handgrip rate of force development at 200 ms in the young ($r = 0.502$, $P = 0.024$) and older ($r = 0.446$, $P = 0.049$) women exhibited the strongest correlation with vertical jump height. *Conclusions:* This investigation showed significantly lower vertical jump height and handgrip peak force and rate of force development values in older compared to younger women. Interestingly, the difference between age groups was larger for jump height than handgrip peak force and rate of force development. This suggests that vertical jump performance may be more severely affected by age than handgrip strength characteristics.

Key words: contraction, muscle power, peak force, rate of force development, women

1. Introduction

Muscle strength and power are essential for fundamental activities of daily living, including walking, stair-climbing, and maintaining postural balance [7], [15]. However, with advanced age, muscle strength and power deficits have been reported to decrease one's ability to perform these daily tasks [15]. Decreases in muscle strength and power have a negative effect on physical function, which may lead to a loss of independence and an elevated risk for dying [24].

Handgrip measurements of peak force and rate of force development (RFD) have been used previously to assess the muscle strength capacities of the upper limb [1]. Vertical jump height is a valid measure of muscle power in the lower limbs [22]. There are several types of vertical jump tests, however, the most

popular test is the countermovement jump [13]. This type of jump makes use of the stretch-shortening cycle, which involves eccentric and concentric muscle work in the countermovement and take-off phases, respectively [9]. Previous studies have reported significantly lower countermovement vertical jump height and handgrip peak force and RFD in older compared to younger adults [6], [16]. These findings support the notion that old age is detrimental to jump height and handgrip strength. However, it is unclear which of these variables is more severely affected by age. Research suggests that aging has a greater impact on muscle strength of the lower limb than that of the upper limb [29]. Because lower limb strength is important for jumping [19], the difference in jump height between young and older adults may be larger than the differences in handgrip peak force and RFD, however, further research is needed to test this hypothesis. As

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mentioned above, muscle strength and power are critical for many functional activities [15]. Thus, comparing handgrip strength and vertical jump height between young and older adults may provide important insight regarding age-related changes in neuromuscular function.

Most studies evaluating handgrip strength only measure peak force [4], [12], [28]. Handgrip measurements of peak force have been shown to be good predictors of performance for movement activities such as walking and rising from a chair [28]. However, because peak force requires greater than 300 ms to be achieved [31], it may not be as functionally relevant for explosive type activities, like jumping. These activities require force to be produced within 120–240 ms [32]. Rapid strength characteristics, which include handgrip RFD, are typically assessed within the first 200 ms of a contraction [26] and therefore, may be better measurements than peak force at explaining the variance associated with explosive performances. Borges et al. [5] showed that handgrip RFD at 200 ms was more strongly correlated with physical performance than handgrip peak force in older adults. However, since the performance data used in this study was limited to mobility [5], it remains unclear whether handgrip RFD at 200 ms or at another time interval (i.e., RFD at 100 ms or peak RFD) correlates better than peak force with vertical jump height.

Ideally, vertical jump height would be tested to assess muscle power of the lower limbs; however, this is not always feasible in clinical settings due to safety concerns [30]. Handgrip peak force and RFD are relatively safe and easy measures to obtain [23]. These measurements have been used as a surrogate for whole-body strength [18], [27], but their correlation with vertical jump height still needs to be established. Investigating such a correlation may help determine which handgrip variables can be relied upon to predict vertical jump ability. It is important to note that most authors investigating the effects of age on handgrip strength and jump height have only tested men [2], [14], [17]. Some authors have investigated these effects in women, but the women that they tested were all sedentary [10], [33]. Additional research examining age-related differences in handgrip strength and vertical jump height in physically-active women is needed. Thus, the purpose of the present study was to compare handgrip strength measurements (i.e., peak force and RFD) and vertical jump height between physically-active young and older women. A secondary aim was to investigate the correlations between handgrip strength measurements and vertical jump height. Based on the

results reported by previous authors [5], [17], we hypothesized that handgrip strength and vertical jump height might be associated with each other and significantly lower in the older compared to the younger adults.

2. Materials and methods

2.1. Participants

Before data collection, an *a priori* power analysis was performed for a between-groups design. Using G*Power software (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany) and effect sizes from relevant research [6], [33], it was determined that a minimum of 19 participants in each group were needed to achieve a statistical power of 0.80 at an alpha level of 0.05. Thus, 20 young (mean \pm SD; age = 21.5 \pm 2.8 years; height = 162.4 \pm 5.6 cm; body mass = 67.9 \pm 14.7 kg) and 20 older (age = 67.0 \pm 5.5 years; height = 163.8 \pm 6.3 cm; body mass = 67.8 \pm 11.4 kg) women were recruited to participate in the present study. Young participants were recruited and tested at the university. Older participants were recruited and tested at a community-based health and wellness facility. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the upper and lower extremities. Participants were classified as being regular exercisers based on their self-reported volume of physical activity (young = 8.9 \pm 5.4 h \cdot wk⁻¹; older = 8.3 \pm 7.1 h \cdot wk⁻¹) [25]. The young and older women participated in walking, jogging, cycling, and/or resistance type exercise. This study was approved by the Texas Tech University Institutional Review Board for human subject research and each participant was informed of the benefits and risks of the investigation before signing an informed consent document.

2.2. Experimental design

This study used a cross-sectional research design to compare vertical jump height and handgrip peak force and RFD variables between young and older women. Each participant reported for testing on two different occasions, separated by 2–7 days. During the first visit, participants were familiarized with the testing procedures by performing several vertical jump and handgrip maximal voluntary contraction (MVC) as-

assessments. During the second visit, participants completed three countermovement vertical jumps followed by three handgrip MVCs with the dominant hand. Hand dominance was self-reported prior to testing as the preferred hand for throwing a ball [3].

2.3. Vertical jumps

Vertical jump assessments were performed on a jump mat (Just Jump Technologies, Huntsville, AL) [30]. For each assessment, participants stood on the jump mat with feet shoulder width apart and hands positioned on the hips. Participants were not allowed to take any steps before performing the vertical jump and a quick descending quarter-squat countermovement was allowed before the ascending take-off phase [11]. For all vertical jumps, participants were instructed to jump up as explosively as possible with both feet at the same time and land on the jump mat in the starting position. The jump mat measured vertical jump height [cm] based on flight time, which was the time that elapsed from the moment the feet left the mat until landing. Each participant performed one practice trial and three official trials of the vertical jump with one minute of recovery between each trial. The greatest vertical jump height of the three trials was used for subsequent analysis [17].

2.4. Handgrip contractions

Handgrip contractions were performed with the dominant hand using a Dynamo Torque Analyzer (Dynamo, Version 1.0, Texas Tech University, Lubbock, TX), as described previously (Fig. 1) [26]. The Dynamo consisted of a microcomputer and a load cell that was equipped with two semi-cylindrical handles for gripping. These handles were attached at either end of the load cell and positioned approximately 4.8 cm apart in accordance with the procedures described by Barbosa et al. [4]. For all testing, participants sat in a chair with their shoulder adducted, elbow flexed at 90°, and forearm and wrist held in a neutral position [12]. Following three submaximal (warm-up) handgrip muscle actions, participants completed three handgrip MVCs with one minute of recovery between each trial. For all MVCs, participants were instructed to squeeze the handles of the load cell “as hard and fast as possible” for a total of 3–4 s, and strong verbal encouragement was given throughout the duration of the contraction [23].

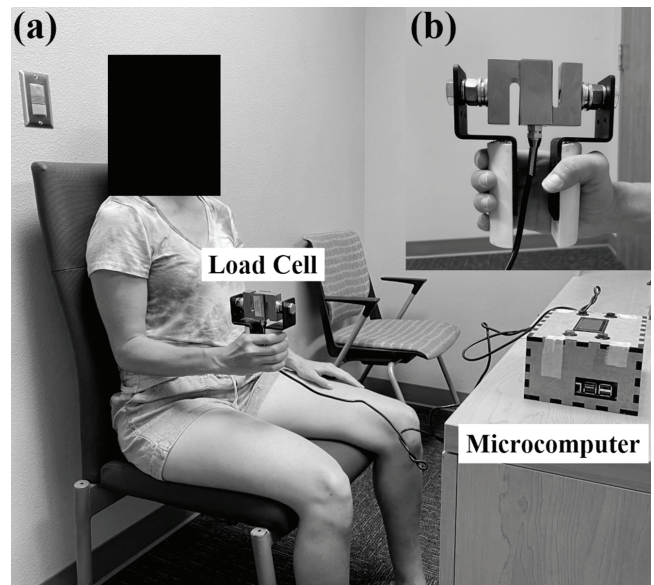


Fig. 1. (a) A participant performing a handgrip maximal voluntary contraction using the Dynamo. The Dynamo consists of two functional components: a load cell and a microcomputer. The load cell was equipped with two semi-cylindrical handles for gripping; (b) An enlarged picture of the handles attached to the load cell is provided

For the MVC assessments, the Dynamo was programmed by the primary investigator to record force from the load cell in Newtons [N]. During each MVC, the scaled force signal from the load cell was sampled, interpolated to 1000 Hz, and processed automatically by the Dynamo. The force signal was low-pass filtered with a zero-phase lag, fourth-order Butterworth filter at a cutoff frequency of 10 Hz [23]. At the start of each MVC, participants applied a light steady baseline force to the handles of the load cell. This baseline force was subtracted from the signal so that the new baseline force value was 0 N [26]. All subsequent analyses were conducted on the filtered and baseline-corrected force signal (Fig. 2).

Peak force was calculated as the highest mean 500 ms epoch. RFD was calculated as the linear slope of the force signal at time intervals of 0–100 (RFD100) and 0–200 (RFD200) ms from contraction onset. Peak RFD was calculated as the highest slope value for any 100 ms epoch that occurred over the initial 200 ms of the force signal. The contraction onset for the Dynamo was set at 5 N [26]. Peak force, peak RFD, RFD100 and RFD200 were calculated and displayed by the Dynamo at the conclusion of each MVC and were normalized to body mass. Of the three MVCs performed, the trial with the highest peak RFD value was selected for analysis [23].

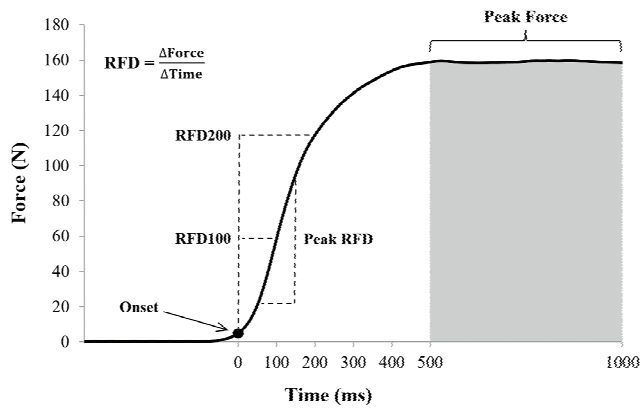


Fig. 2. Example of a processed force signal taken from a participant during a handgrip maximal voluntary contraction. The force signal produced during the contraction was used to measure handgrip peak force and rate of force development (RFD) characteristics.

Peak force was calculated as the highest mean 500 ms epoch. RFD was calculated as the linear slope of the force signal ($\Delta\text{force}/\Delta\text{time}$) at time intervals of 0–100 (RFD100) and 0–200 (RFD200) ms from onset. Peak RFD was calculated as the highest slope value for any 100 ms epoch that occurred over the initial 200 ms of the force signal

2.5. Statistical analyses

Independent samples *t*-tests were used to compare demographics, vertical jump height, and handgrip strength measurements (peak force and RFD variables) between the young and older women. Cohen's *d* effect sizes [8] and percent differences (% Δ) were calculated for each between-group comparison. Pearson correlation coefficients (*r*) were calculated separately for the young and older women to examine the relationships between handgrip strength measurements and vertical jump height. The coefficient of determination (r^2) was reported for each correlation to indicate the amount of variance explained by the handgrip strength measurements. Statistical analyses were conducted using SPSS

software (Version 26, IBM Corp, Armonk, NY), and an α level of $P \leq 0.050$ was used to determine statistical significance.

3. Results

There were no significant differences between the young and older women for height ($P = 0.445$, $d = 0.24$, % $\Delta = 0.9\%$), body mass ($P = 0.986$, $d = 0.01$, % $\Delta = 0.1\%$), or volume of physical activity ($P = 0.785$, $d = 0.09$, % $\Delta = 6.2\%$). The means, SDs, *P* values, Cohen's *d* effect sizes and percent differences between groups for vertical jump height and handgrip peak force and RFD variables are shown in Table 1. The older women exhibited significantly lower vertical jump height, peak force, peak RFD, RFD100 and RFD200 than the younger women ($P \leq 0.028$, $d \geq 0.70$). A larger difference was observed between the groups for vertical jump height (% $\Delta = 41\%$) than handgrip peak force and RFD (% $\Delta = 12\text{--}17\%$).

Positive correlations were observed between vertical jump height and handgrip RFD200 ($r = 0.502$, $r^2 = 0.252$, $P = 0.024$) and peak RFD ($r = 0.453$, $r^2 = 0.205$, $P = 0.045$) for the younger women. Positive correlations were also observed between vertical jump height and handgrip RFD200 ($r = 0.446$, $r^2 = 0.199$, $P = 0.049$) and peak RFD ($r = 0.408$, $r^2 = 0.166$, $P = 0.074$) for the older women, although the latter correlation did not reach statistical significance. There were no significant correlations between vertical jump height and handgrip peak force (young: $r = 0.389$, $r^2 = 0.151$, $P = 0.090$; older: $r = 0.311$, $r^2 = 0.097$, $P = 0.183$) or RFD100 (young: $r = 0.366$, $r^2 = 0.134$, $P = 0.113$; older: $r = 0.382$, $r^2 = 0.146$, $P = 0.096$) for either age group. The scatterplots for these correlations are shown in Fig. 3.

Table 1. Means \pm SDs, *P* values, Cohen's *d* effect sizes, and percent differences (% Δ) between groups for vertical jump height and handgrip peak force and RFD variables.

Variable	Young (<i>n</i> = 20)	Older (<i>n</i> = 20)	<i>P</i> value	<i>d</i>	% Δ
Vertical Jump Height [cm]	34.37 \pm 5.89	20.31 \pm 3.77*	< 0.001	1.63	41%
Handgrip					
Peak Force [N·kg ⁻¹]	2.66 \pm 0.45	2.35 \pm 0.38*	0.028	0.70	12%
Peak RFD [N·s ⁻¹ ·kg ⁻¹]	16.40 \pm 2.93	13.64 \pm 2.64*	0.003	0.89	17%
RFD100 [N·s ⁻¹ ·kg ⁻¹]	15.72 \pm 3.33	13.20 \pm 2.96*	0.016	0.75	16%
RFD200 [N·s ⁻¹ ·kg ⁻¹]	10.84 \pm 1.61	9.26 \pm 1.57*	0.003	0.90	15%

* Significantly lower vertical jump height and handgrip peak force and RFD variables for the older women than the young women ($P \leq 0.050$). RFD = rate of force development.

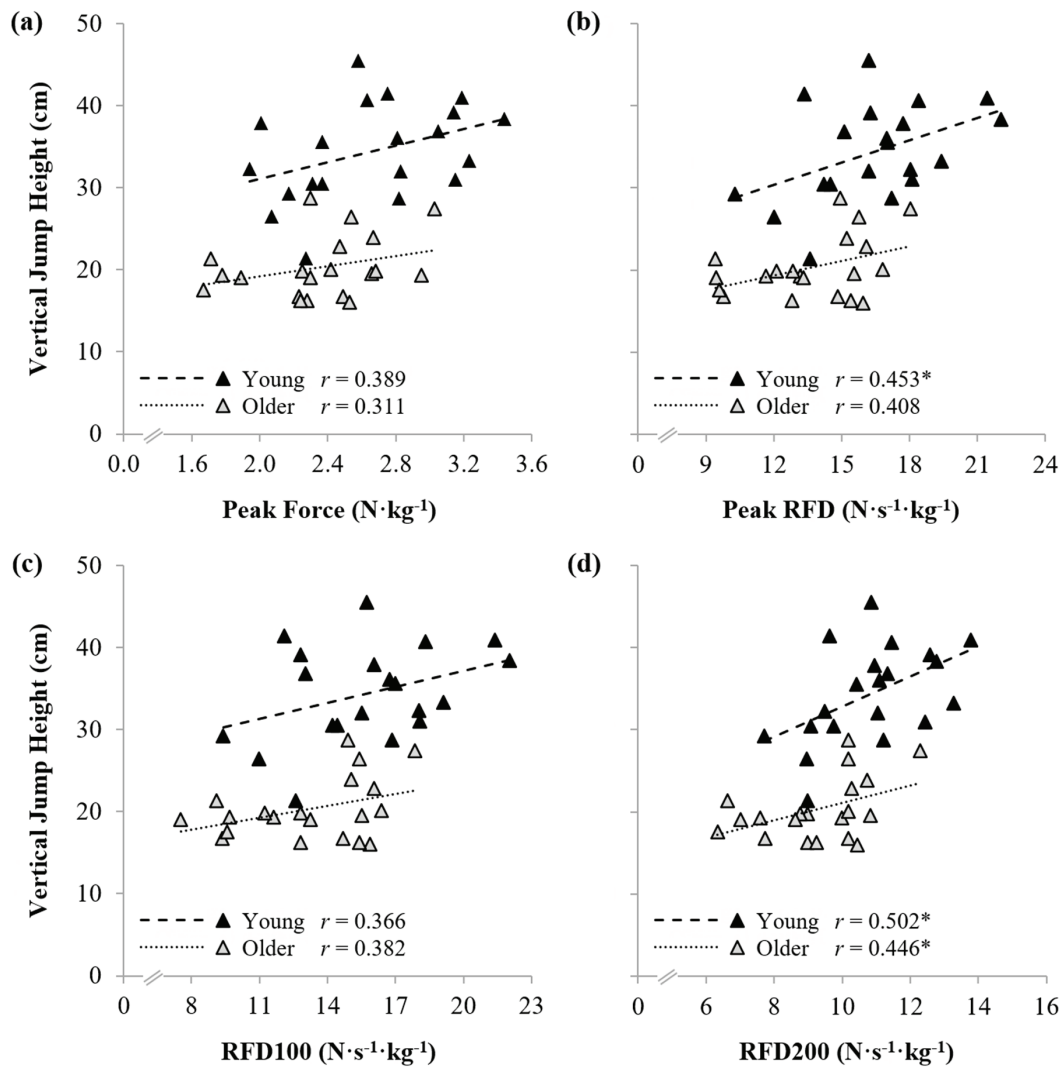


Fig. 3. Scatterplots of the correlations between vertical jump height and handgrip (a) peak force, (b) peak RFD, (c) RFD100 and (d) RFD200 for the young and older women. RFD = rate of force development.

*Denotes a statistically significant correlation ($P \leq 0.050$)

4. Discussion

Our findings revealed significantly lower vertical jump height and handgrip peak force and RFD values for the older compared to the younger women (Table 1). A larger difference was observed between the groups for vertical jump height than handgrip peak force and RFD. In addition, there were significant correlations for the young and older women between vertical jump height and handgrip RFD200, however, there were no correlations for either age group between vertical jump height and handgrip peak force or RFD100 (Fig. 3).

Previous studies have demonstrated that vertical jump height and handgrip peak force and RFD are significantly lower in older compared to younger adults [6], [16]. In this study, we also found lower vertical

jump height and handgrip peak force and RFD values in older compared to younger women (Table 1). However, a key finding of the present study was that the difference between groups for jump height (41%) was substantially larger than that for handgrip peak force (12%) and RFD (15–17%). This larger difference perhaps reflects an enhanced age-related impairment in the ability to jump vertically versus the ability to apply force with the upper limb. Research suggests that aging causes greater strength decrements in the lower-limb muscles [29]. Older adults use their lower limbs disproportionately less than their upper limbs, resulting in greater strength loss [20]. Because lower-limb strength is critical for jumping [19], a greater age-related decrease in this parameter may explain why a larger difference in jump height was observed between the young and older women in the present study. Such

a difference may also in part be a result of the complexity of the vertical jump in relation to the handgrip test. Indeed, the vertical jump is a more complex task, where muscle weakness and problems with balance and motor coordination may combine to elicit a greater reduction in performance [21]. Future studies using a more comprehensive set of performance-based measures (i.e., lower-limb and handgrip strength, jump height, balance, coordination, etc.) are needed to further examine these findings.

Although the difference in jump height between the young and older women in this study was substantial (41%), it was not as large as the age-related differences in jump height reported by previous authors [6], [11]. These authors found jump height values that were 56–70% lower in older compared to younger women. However, the older women that they tested were on average over 70 years of age [6], [11]. Testing such women may have contributed to a larger age-related decline in vertical jump height than that observed in the present study, which tested older women with a lower mean age of 67 years. An important aspect of the present study was the physical activity levels of the participants. The older women in our study were regular exercisers and participated in a similar volume of physical activity as the younger women (8.3 vs. 8.9 h·wk⁻¹). Participating in such a high volume of physical activity may be another reason why we found a smaller difference in vertical jump height between age groups compared to that of previous studies. The physical activity levels of the older participants may explain the age-related differences in handgrip peak force and RFD values that we observed (12–17%), which were also much smaller than those reported previously (25–38%) [16], [33]. Taken together, these findings suggest that a physically active lifestyle may attenuate the decreases in jump height and handgrip strength commonly reported as a consequence of aging. Because jump height and handgrip strength are associated with physical function [19], [26], attenuating the declines in these parameters via physical activity may be a critical factor in the preservation of functional independence in older adults.

In clinical practice, muscle strength is predominantly assessed by measuring handgrip peak force [4], [12], [28]. A unique feature of the present study was the assessment of handgrip RFD. We found significant positive correlations between handgrip RFD200 and jump height in young and older women (Fig. 3). These correlations provide support that handgrip RFD at 200 ms from contraction onset may be an effective measure at determining one's jumping ability. Handgrip RFD200 may also serve as a good variable for

identifying age-related declines in neuromuscular function. The predictive capacity of such a variable has important clinical implications [29]. For example, in an ideal world, clinicians would assess the muscle power of patients by testing their vertical jump height. However, this is not always feasible due to patient-related factors and safety concerns [23], [30]. Thus, an easy, safe, and practical measure of performance, such as handgrip RFD, that is predictive of jump height may be a preferable alternative. Handgrip measurements of RFD do not require large or expensive equipment [26]. More importantly, unlike vertical jump assessments, in which often dedicated staff are required to prevent falls during testing [30], [34], handgrip RFD measurements can be safely administered while sitting [23] and thus, may be more desirable in certain research or clinical situations where staff is limited.

Despite a significant correlation for the young and older women between jump height and handgrip RFD200, no such correlation existed for either age group between jump height and handgrip peak force or RFD100 (Fig. 3). These findings suggest that handgrip RFD at 200 ms correlates better than handgrip peak force and RFD at 100 ms with vertical jump performance. Many explosive movement activities, including jumping, require force to be produced within 120–240 ms [32]. Because 200 ms falls within this time window, RFD200 may be a more functionally-relevant characteristic of vertical jump performance than other strength measurements. This includes measurements of peak force, which typically require over 300 ms to be achieved [31]. Thus, the possibility of greater functional relevance between rapid strength at 200 ms and vertical jumping may explain why a larger portion of the variance in jump height could be accounted for in the present study by handgrip RFD200. It is interesting to note that the correlation between handgrip peak RFD and jump height was statistically significant in the younger women and approached statistical significance in the older women (Fig. 3). Such findings indicate that handgrip peak RFD, like RFD200, may be able to predict jumping ability. Additional research with larger sample sizes is needed to further examine the importance of handgrip RFD variables as they relate to jump height.

5. Conclusions

This investigation showed significantly lower vertical jump height and handgrip peak force and RFD

values in older compared to younger women (Table 1). Interestingly, the difference between age groups was larger for jump height than handgrip peak force and RFD. This suggests that vertical jump performance may be more severely affected by age than handgrip strength characteristics. In our study, there were significant correlations for the young and older women between jump height and handgrip RFD200 but not peak force or RFD100 (Fig. 3). These findings indicate that handgrip RFD at 200 ms correlates better than other strength measurements with vertical jump height and thus, may be a more effective variable at determining one's jumping performance. Given the predictive capacity of such a variable, clinicians and other practitioners may want to consider using handgrip measurements of RFD200 in their current test battery. These measurements may provide practitioners with an additional evaluation tool to help in identifying individuals with poor jump height and possibly overall functional ability.

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