International Journal of EXERCISE SCIENCE

Original Research

The Generality of Strength: Relationship between Different Measures of Muscular Strength in Older Women

JOÃO PEDRO NUNES[†1], PAOLO M. CUNHA[†1], MELISSA ANTUNES[‡1], BRUNA D. V. COSTA[†1], WITALO KASSIANO[*1], GABRIEL KUNEVALIKI[*1], ALEX S. RIBEIRO[‡1,2], and EDILSON S. CYRINO[‡1]

[1]Metabolism, Nutrition, and Exercise Laboratory. Physical Education and Sport Center, Londrina State University. Londrina, PR, Brazil; [2]University of Northern Paraná, Center for Research in Health Sciences. Londrina, PR, Brazil.

*Denotes undergraduate student author, †Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(3): 1638-1649, 2020. The aims of this study were: (i) to analyze the relationship between the performance of different measures of muscular strength, and (ii) to identify which measurements present a greater relationship with an overall strength score. Sixty older women (aged 69 ± 6 years) were submitted to muscular strength measurements from isotonic, isokinetic, and isometric tests. An overall-strength score was generated with *z*-scores of the values obtained in all tests. Interquartile intervals were created for each measure and the overall-strength score. Pearson's r (0.463-0.951, $p < 0.05$) and Cronbach's α (0.500-0.966) suggested that subjects had relatively similar strength performance compared to their peers in the different tests. Greater associations were observed between tests for similar tasks. In addition, strong-magnitude associations were revealed between all the tests and the overall-strength score (r = 0.710-0.806; α = 0.760-0.846). Factor analysis identified that only two principal components may be sufficient to explain the strength of the sample. All strength measures had high loadings (0.716-0.916) on a common factor with 1 component. The associated eigenvalue with 2 components was 6.8 (84% of the variance). The present results support the phenomenon of the generality of strength in older women. Although greater correlations were observed for tests performed at the same joint, movement, or type of muscular action, the eight tests satisfactorily represented a measure of general muscular strength cross-sectionally.

KEY WORDS: Elderly; specificity; resistance training; testing; isokinetic dynamometer; one-repetition maximum test

INTRODUCTION

Muscular strength is a physical capacity of the neuromuscular system with high relevance for sports performance, well as to perform daily activities. Furthermore, it has been considered as one of the essential global health-status markers (6, 8, 14, 35). In the elderly, strength is related to independent living and quality of life, so that it has been observed that higher values of muscular strength are associated with being active in leisure time during old age (28). A growing body of evidence demonstrates that increased levels of muscular strength are also related to better cellular health (33), lower levels of type 2 diabetes mellitus, risk of depression, and cardiovascular risk (25–27). Moreover, the realization of muscle-strengthening activities presents a dose-dependent relation with mortality (15). However, higher levels of lower limb-muscular strength seem to be more relevant than muscle-strengthening activities *per se* for reducing the risk of death (14).

Several tools have been used to measure muscular strength, such as one-repetition maximum (1RM) tests, isometric or isokinetic dynamometry (3,35). The extrapolation of the muscular strength revealed in a determined test for other tasks has been widespread (11). However, some studies demonstrated conflicting results for this phenomenon (2–7, 3, 17-19, 22-24), known as "generality of strength" (11). For instance, strong correlations were found in young male adults for the bench press exercise performed from 1RM, hydraulic, and isokinetic tests (22). On the other hand, a weak correlation was revealed in resistance-trained men for 1RM tests performed in the bench press and leg press exercises (24). A week correlation also was reported between handgrip strength and lower- and upper-limbs 1RM tests in young athletes (23). In older adults, Felicio et al. (17) also verified that handgrip strength was not associated with the isokinetic performance of the knee joint, although this is not a universal finding (2–7, 19). The main point that seems to determine whether there is a strong correlation between different tests appears to be the similarity concerning which and how many muscles/joints are directly involved, as well as the type of muscular action and velocity that it is performed. However, most studies have limited itself to compare and correlate the performance of only two tests or devices. Therefore, it remains to be explored to what extent there are significant correlations (or the lack thereof) between several strength measures.

Considering that the method of strength assessment is essential when exploring its association with other outcomes (3, 6, 8–11), it would be beneficial to determine which test would most represent the overall whole-body strength status if only one test could be selected. Indeed, it has been highlighted that "a true measure of strength" remains elusive (3, 10, 11). Compared to upper limb strength, lower limb strength has more substantial clinical and practical relevance for the elderly since it determines functional fitness to perform daily living activities, such as walking and stair climbing. With conflicting results in the literature (2–4, 17, 19), it is also necessary to investigate whether upper limb or trunk strength measures represent the strength of an individual similar to that of lower limb tests. Therefore, the aim of the current study was twofold: (i) to explore the relationship between the performances on different strength tests, and (ii) to verify which of them presents the higher relation with an overall (general) strength score. It was hypothesized that the results of the performance on the different tests would be correlated with each other, with a higher association between tests for similar tasks.

METHODS

Participants

The data of the present study were collected on April 2019, and it is from a part of a longitudinal research project named "Active Aging Longitudinal Study" whose purpose is to analyze the effects of supervised, structured, and progressive resistance training programs on neuromuscular, morphological, physiological, metabolic, and behavioral outcomes in older women. The sample was previously selected through an interview and clinical anamnesis. All participants meet the following inclusion criteria: ≥ 60 years old, female, physically independent, free from cardiac or orthopedic dysfunction and musculoskeletal disorders that could impede physical exercise, not receiving hormonal replacement therapy, not be involved in the practice of regular physical activity performed more than once a week over the last five months before the start of the study, and immediate release from a cardiologist (resting 12-lead electrocardiogram test, personal interview, and treadmill stress test when deemed necessary) to practice exercise without any restriction. Sixty-five older women (≥ 60 years) participants were selected, but five did not attend for all testing, leaving a total of 60 participants. Although they were members of the mentioned research project, they were untrained for five months. The characteristics of the sample are presented in Table 1. Twenty participants were randomly selected (random.org) and were asked to perform handgrip and isokinetic tests for two days (separated by 48-72 hours) for obtaining reliability scores. Written informed consent was obtained from all participants after providing a detailed description of the study procedures.

Protocol

This study was carried out over two weeks, with the first week dedicated to 1RM and anthropometric measurements and the second week to muscular strength tests in the handgrip and isokinetic dynamometers. The investigation was approved by the University Ethics Committee. All procedures were conducted following the ethical standards of the Helsinki Declaration and complied with the ethical issues of the International Journal of Exercise Science (31). No adverse event occurred during the study period.

Handgrip strength was assessed on the dominant hand of the participants with a hydraulic hand dynamometer, (Saehen, SH5001 model. Changwon, South Korea). Participants remained seated on a chair with back supported, feet on the floor, arms at the side of the body, elbow flexed at 90°, and forearm in a neutral position. The dynamometer handle was adjusted according to the size of each hand. Ten submaximal grips were used as a warm-up, and the testing procedure was initiated one minute after the warm-up. Three attempts of five seconds of maximum contraction were allowed for the participants. The rest period was one minute between each attempt. Verbal encouragement was provided throughout each test. The maximum value in the three attempts was recorded and expressed in kilograms (kg). Standard error of measurement (SEM) and intraclass correlation coefficient (ICC) were 1.35 kg and 0.911, respectively.

Maximal dynamic strength was evaluated using 1RM tests assessed on the chest press, knee extension, and preacher curl exercises (Ipiranga, Fitness Line. Presidente Prudente, Brazil), in this order. Three 1RM testing sessions were performed in the morning, separated by 48 hours. In each session, participants performed a warm-up of 10-15 repetitions with approximately 50% of the estimated load to be used in the first attempt, followed by three maximal attempts. For the first day of testing, the load selected firstly was based on the researchers' experience and perception of the difficulty (effort) in which participants performed the warm-up. If the first attempt was completed, weight was added for the second and third attempts (3-10% of the previous attempt). If an attempt was not successful, weight was removed in the same proportion. The rest period was three to five minutes between each attempt and five minutes between exercises. The load for the first attempt of the second and third sessions was the maximal obtained in the previous session. Three experienced researchers supervised all sessions to help ensure safety and integrity. The technique for each exercise was standardized and continuously monitored to ensure reliability. During the 1RM tests, the participants were encouraged to attempt to accomplish two repetitions with the selected load. Verbal encouragement was provided, accompanied by clapping. The 1RM was recorded as the heaviest load lifted in which the participant was able to complete only one maximal execution among the three sessions (30). The SEM and ICC obtained for the current sample were satisfactory for chest press (SEM = 1.71 kg; ICC = 0.978), knee extension (SEM = 2.03 kg; ICC = 0.974), and preacher curl (SEM = 0.36 kg; ICC = 0.994).

Isokinetic (ISOK) and isometric (ISOM) knee extension strength were evaluated by peak torque for concentric actions. Upon arriving at the assessment laboratory, participants were positioned in the sitting position according to the anatomical position (85° hip flexion) on the Biodex dynamometer (Biodex Medical Systems Inc., System 3 model. Shirley, USA). The dynamometer lever arm attachment was aligned with the lateral epicondyle of the femur. Also, it was secured with straps around the medial malleoli, according to the manufacturer's guidelines. Another strap was placed over the thigh of the participants' dominant leg. Three more straps were placed to keep stabilized shoulders, torso, and waist. The total range of motion during the isokinetic test was 90°. The ISOK evaluation was conducted at angular velocities of 60º/s, 180º/s, and 300º/s. The ISOM evaluation was performed with the knee flexed at 60º, considering 90º as perpendicular to the horizon position. Gravity correction was applied, and cushing was set at a moderate, both according to the manufacturer's specifications. Ten submaximal repetitions at 60º/s were used as a warm-up. The testing procedure was initiated one minute after the warm-up.

Participants performed ISOK tests in two sets of five, five, and seven repetitions at velocities 60º/s, 180º/s, and 300º/s, respectively. For the ISOM test, they performed three sets of one repetition of five seconds. Participants were instructed to support the hands on the shoulders with the arms crossed during the tests (32) and to perform the movement (reciprocal extension and flexion in the isokinetic test) as fast and as strong as possible. Verbal encouragement was given during the tests, and visual feedback was not allowed. Besides, participants were coached to exert maximal effort using incentive phrases such as "force up", "force down", "go faster and stronger", accompanied by clapping. The rest intervals were one minute between sets and two minutes between different muscle actions. The maximum value in each muscle action was obtained and expressed in newton-meter (Nm). The tests were performed in the same sequence (ISOK60, ISOK180, ISOK300, ISOM), by the same evaluator (32). The SEM and ICC were satisfactory for ISOK60 (SEM = 3.55 Nm; ICC = 0.983), ISOK180 (SEM = 3.31 Nm; ICC = 0.961), ISOK300 (SEM = 2.91 Nm; ICC = 0.926), and ISOM (SEM = 9.19 Nm; ICC = 0.923).

Statistical Analyses

The Shapiro-Wilk test verified data distribution. *Z*-scores were created for the values obtained of the performance on all strength tests. For the isokinetic tests (ISOK60, ISOK180, ISOK300, and ISOM), a unique *z*-score was generated by the simple mean of the *z*-scores of the four isokinetic tests. An overall-strength score was created using the mean of *z*-scores of values of the handgrip, chest press 1RM, knee extension 1RM, preacher curl 1RM, and isokinetic tests. Pearson's correlation (r) was used to verify the relationship between analyzed variables. Interquartile intervals were created for each test and the overall-strength score. Cronbach's α was used to verify the reliability on classifying the subjects according to the interquartile intervals of strength performance between the different tests. Item-corrected Pearson's *r* and Cronbach's α were performed between the strength measures and the overall strength score (by removing each analyzed measure from the overall score separately). Associations of 0.00–0.20 were considered very weak, 0.21–0.40 as weak, 0.41–0.60 as moderate, 0.61–0.80 as strong, and ≥ 0.81 as very strong. Comparisons between correlations were made based on the confidence interval of Fisher's *z*-value converted from the *r*-value (20). ICC and SEM were used to analyze test-retest reproducibility (21). Factor analysis was performed using principal component analysis (extraction, without rotation) with standardized values (5). A $p < 0.05$ was accepted as statistically significant. The data were expressed as mean, standard deviation, and 90% confidence intervals, and were stored and analyzed using Jamovi (v. 1.0.7, The Jamovi Project) or the spreadsheets quoted above (20,21).

RESULTS

Table 1 presents the values of sample characteristics and the results of the performance on strength tests. Table 2 presents the results of the correlations (Pearson's *r*) and reliability (Cronbach's α) of strength measures between them all. The correlation of the handgrip strength with the other measures was of moderate-to-strong magnitude (r = 0.479–0.633), whereas the correlation of the performance within the three 1RM tests was strong (r = 0.601–0.757), and the correlation within the four isokinetic tests was very strong (r = 0.833–0.951). The correlations of the isokinetic knee extension measures with the knee extension 1RM were of strong magnitude (r = 0.642–0.719), while they were weaker with all the other tests (r = 0.463–0.609).

Table 1. General characteristics of the sample and the results of the performance on different strength tests (n = 60).

Variables	Mean	SD	Min	Max
Age (years)	68.7	5.9	60.3	85.4
Body mass (kg)	68.7	11.5	42.6	96.1
Stature (cm)	1.55	0.06	1.43	1.68
Body mass index (kg/m^2)	28.6	4.3	18.0	40.0
Handgrip (kg)	28.0	4.7	18.0	41.0
Chest press 1RM (kg)	57.4	13.3	22.0	88.0
Knee extension 1RM (kg)	59.6	16.1	20.0	112.0
Preacher curl 1RM (kg)	27.8	4.0	19.0	37.0
Knee extension ISOK60 (Nm)	104.7	24.8	57.9	168.1
Knee extension ISOK180 (Nm)	67.6	15.6	33.2	116.0
Knee extension ISOK300 (Nm)	51.2	12.3	28.3	93.2
Knee extension ISOM (Nm)	127.9	32.4	74.8	218.5

1RM = one-repetition maximum. ISOK60, ISOK180, ISOK300 = isokinetic at 60°/s, 180°/s, and 300°/s angular velocities. ISOM = isometric.

Similarly, the reliability between the interquartile of handgrip strength with the other measures was of moderate-to-strong magnitude (α = 0.571–0.696), whereas reliability within the three 1RM performances was strong (α = 0.611–0.790), and the reliability within the four isokinetic measures was almost perfect (α = 0.846–0.966). The reliability of the ISOK and ISOM knee extension with the knee extension 1RM was of strong magnitude (α = 0.673–0.780), while with the other 1RM tests was weaker (α = 0.500–0.598), as well for handgrip (α = 0.571–0.684). Standardized reliability for the eight measures were almost perfect (α = 0.937; item-dropped range: 0.922–0.937).

Figure 1 displays scatterplots of the relations between the overall-strength score and the strength tests. All the measures presented strong relationships with the overall score (r = 0.710–0.806, $p < 0.001$), as well there was observed a strong reliability between the overall strength and the handgrip (α = 0.770), chest press 1RM (α = 0.760), knee extension 1RM (α = 0.790), preacher curl 1RM (α = 0.800), ISOK60 (α = 0.846), ISOK180 (α = 0.828), ISOK300 (α = 0.770), and ISOM (α = 0.790).

Factor analysis identified that only two principal components (with eigenvalue ≥ 1.0) were sufficient to explain the strength outcome of the sample. All strength measures had high loadings on a common factor with 1 component (handgrip = 0.736; chest press 1RM = 0.755; knee extension 1RM = 0.852; preacher curl 1RM = 0.716; ISOK60 = 0.907; ISOK180 = 0.916; ISOK300 = 0.891; ISOM = 0.883). The associated eigenvalue with 1 component was 5.6 (70% of the variance), while with 2 components was 6.8 (84% of the variance).

DISCUSSION

The main finding of the current study was that the eight measures of muscular strength presented significant and strong correlations between them. These results were similarly found for the interquartile classifications, that is, participants tend to repeat their positions (i.e., rank) in the different manifestations of muscular strength among their peers. A new way of analyzing muscular strength was proposed by generalizing a unique score with the z-scores obtained from the performance of various tests. This indicator gives an overview of muscular strength levels based on the evaluation of different manifestations of strength.

Considering that sometimes using a single test may inform about the overall strength of the subjects in a limited way (10), an index that takes into account various kinds of strength is expected to be better when representing the status of this variable. Of note, all tests presented here a strong correlation (a high percentage of shared variance) with the overall score. Moreover, in view of the results obtained with the principal component analysis, the use of only 2 variables (among the 8 tested here) can represent almost the entire strength outcome. This occurred because the measures have a low variability, and they were highly correlated with each other, as presented in Table 2. That is, a smaller number of variables are necessary to explain the subjects' strength, resulting in savings in time and resources in future works that will use similar samples and tests, without significant loss of information. Thus, any upper or lower body test can be chosen to represent the overall total-body strength level cross-sectionally; confirming the presence of the "generality of strength" in older women.

Table 2. Pearson's correlations between all strength tests for linear values and Cronbach's α analyses for interquartile scores ($n = 60$).

	Pearson's r	Cronbach's α
Handgrip		
Chest press 1RM	0.633 (0.484, 0.746)	0.696 (0.548, 0.795)
Knee extension 1RM	0.630 (0.480, 0.744)	0.684 (0.531, 0.787)
Preacher curl 1RM	0.620 (0.468, 0.737)	0.684 (0.531, 0.787)
Knee extension ISOK60	0.520 (0.344, 0.661)	0.661 (0.496, 0.772)
Knee extension ISOK180	0.503 (0.323, 0.648)	0.571 (0.363, 0.712)
Knee extension ISOK300	0.479 (0.295, 0.629)	0.611 (0.422, 0.738)
Knee extension ISOM	0.609 (0.454, 0.728)	0.684 (0.531, 0.787)
Chest press 1RM		
Knee extension 1RM	0.757 (0.648, 0.836)	0.790 (0.688, 0.859)
Preacher curl 1RM	0.681 (0.546, 0.781)	0.707 (0.565, 0.803)
Knee extension ISOK60	0.517 (0.340, 0.658)	0.598 (0.403, 0.730)
Knee extension ISOK180	0.533 (0.360, 0.671)	0.585 (0.383, 0.721)
Knee extension ISOK300	0.501 (0.321, 0.646)	0.571 (0.363, 0.712)
Knee extension ISOM	0.495 (0.314, 0.641)	0.500 (0.257, 0.663)
Knee extension 1RM		
Preacher curl 1RM	0.601 (0.444, 0.722)	0.611 (0.422, 0.738)
Knee extension ISOK60	0.680 (0.545, 0.781)	0.780 (0.674, 0.852)
Knee extension ISOK180	0.719 (0.597, 0.809)	0.718 (0.581, 0.810)
Knee extension ISOK300	0.671 (0.533, 0.774)	0.707 (0.565, 0.803)
Knee extension ISOM	0.642 (0.496, 0.753)	0.673 (0.514, 0.780)
Preacher curl 1RM		
Knee extension ISOK60	0.510 (0.332, 0.653)	0.624 (0.441, 0.747)
Knee extension ISOK180	0.516 (0.339, 0.658)	0.585 (0.383, 0.721)
Knee extension ISOK300	0.510 (0.332, 0.653)	0.529 (0.301, 0.683)
Knee extension ISOM	0.463 (0.276, 0.616)	0.529 (0.301, 0.683)
Knee extension ISOK60		
Knee extension ISOK180	0.929 (0.892, 0.953)	0.913 (0.871, 0.941)
Knee extension ISOK300	0.892 (0.838, 0.929)	0.905 (0.859, 0.936)
Knee extension ISOM	0.902 (0.852, 0.935)	0.889 (0.835, 0.925)
Knee extension ISOK180		
Knee extension ISOK300	0.951 (0.925, 0.968)	0.966 (0.949, 0.977)
Knee extension ISOM	0.859 (0.790, 0.906)	0.846 (0.771, 0.896)
Knee extension ISOK300		
Knee extension ISOM	0.833 (0.753, 0.889)	0.855 (0.785, 0.902)

Note. All analyses reached statistical significance ($p < 0.05$). ISOK60, ISOK180, ISOK300 = isokinetic at 60°/s, 180°/s, and 300°/s angular velocities. ISOM = isometric. Data are presented as Pearson's r and Cronbach's α values and 90% confidence intervals (lower, upper limits).

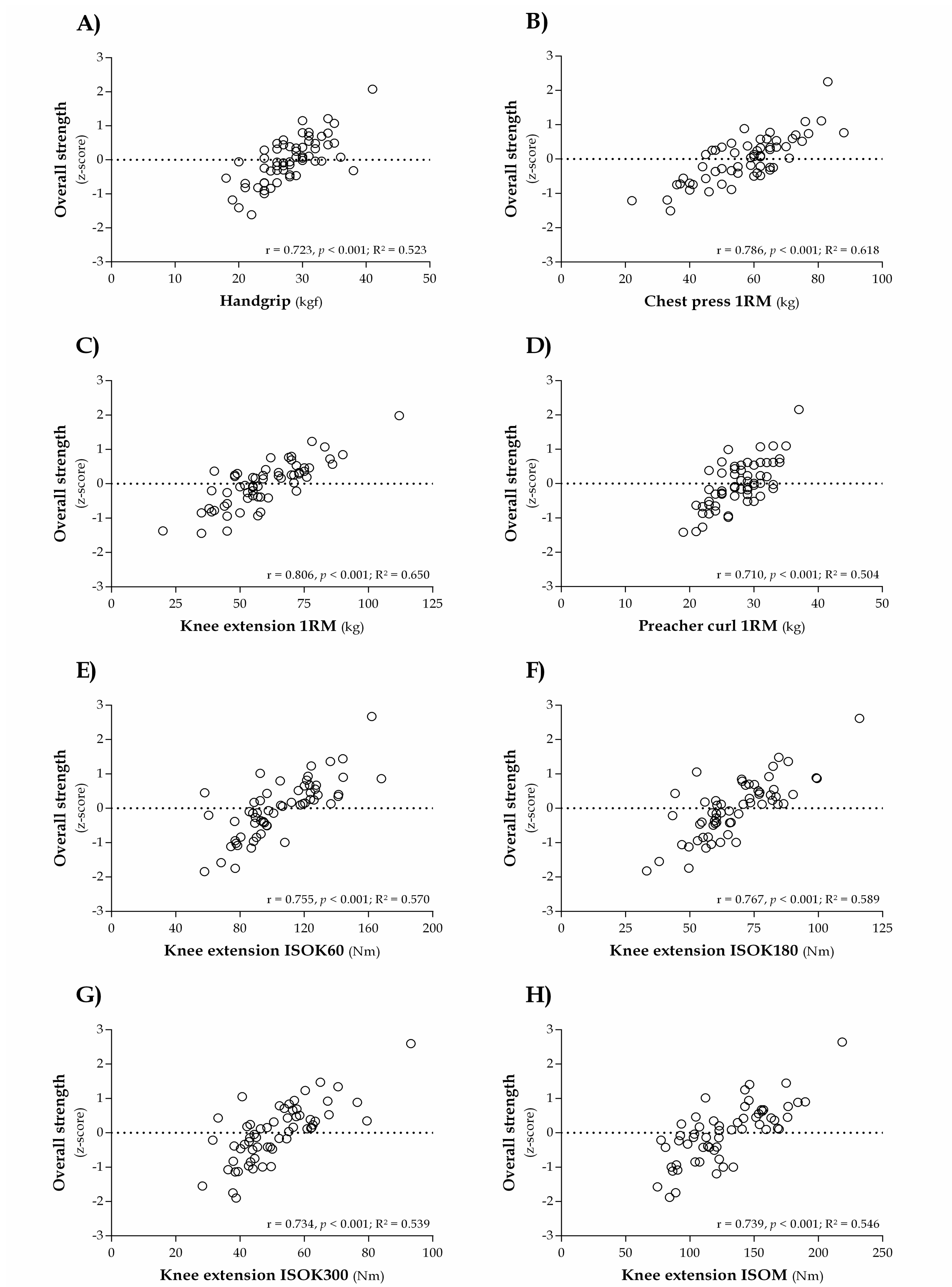

Figure 1. Scatterplots of the correlations between the item-corrected overall-strength score and all the strength measures. 1RM = one-repetition maximum. ISOK60, ISOK180, ISOK300 = isokinetic at 60°/s, 180°/s, and 300°/s angular velocities. ISOM = isometric.

Scores of correlation and reliability were higher when tests were performed for the same joint, movement, or type of muscular action. This result is in line with another study that also verified strong positive correlations (r = 0.750–0.930) between knee extension 1RM and ISOK and ISOM tests in older adults (36). This finding is likely related to the similarity in joint position, the single-joint movement, and the open-chain characteristics of the five knee extension tests. However, the associations between the knee extension 1RM and the four isokinetic knee extension measures were few lower (sometimes significant; according to the confidence intervals of Fisher's z-values) compared to the associations of the four isokinetic knee extension measures within themselves (Table 2); although all were considered as strong magnitude. Some factors may explain why the 1RM presented slight differences when compared to the other tests. While the 1RM was done bilaterally, the ISOK and ISOM were assessed in the same device and unilaterally. Besides the specific task is somewhat different, if there was an asymmetry in the strength production capacity between limbs, the ability of a bilateral strength test to predict a unilateral test would be reduced. Also noteworthy is that the correlations within the five knee extension tests (1RM and on the isokinetic device) were stronger compared to their correlations with the other tests, which indicates that the generality of muscular strength indeed seems to be dependent on the specificity of the test (3, 22, 36).

Additionally, one of the reasons it is important to evaluate muscular strength in elderly individuals is because it is a physical capacity determining functional fitness (1, 16, 18). Although assessing functional fitness through tests that have higher relation to daily living activities (e.g., habitual gait speed, chair rise, stair climb) may provide better information about autonomy and quality of life in older adults, measures of muscular strength have been used mainly as indicators of functional capacity and associated with a variety of functional tests (2, 12, 13, 18, 19, 29, 34). In light of the results obtained in the present investigation, all eight tests may be able to offer a valid measure of functionality in older adults in a cross-sectional manner. Future studies should analyze whether the longitudinal changes in muscular strength measures are also correlated with each other and functional fitness tests.

This study has some concerns that should be addressed. The results of the present investigation are limited to physically independent older women. Therefore, extrapolations to other populations with different age, sex, and autonomy degree should be made with caution, although according to findings of Verdijk et al. (36), results seem to be independent of age and sex. Finally, some external factors such as physical activity levels, dietary intake, and mood status could not be monitored during the study period, hindering the ability to determine whether these aspects exerted an influence on the ability to reach real maximum performance during tests. However, high test-retest reproducibility was observed for the measures explored herein, as described in the methods section.

In conclusion, the present results indicate that the performance on handgrip dynamometer, 1RM on the chest press, knee extension, preacher curl, and isokinetic and isometric knee extension tests are all correlated between themselves and with the overall-strength score. Thus, the eight tests can be chosen to represent the strength level in older women. The eight tests satisfactorily represented a measure of general muscular strength. Based on these results, coaches, strength and conditioning professionals, and clinicians can decide what test to choose when assessing strength level in older women. Given the feasibility and low-cost of performing handgrip and 1RM tests, these can be used with no significant impairment on the quality of measure compared to the tests realized on an isokinetic dynamometer device, which is considered the gold standard. For instance, grip strength can be recommended as a stand-alone measure or as a component of a small battery of measurements for identifying health status in the elderly (6).

REFERENCES

1. ACSM. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. Med Sci Sports Exerc 43(7): 1334–59, 2011.

2. Alonso AC, Ribeiro SM, Luna NM, Peterson MD, Bocalini DS, Serra MM, et al. Association between handgrip strength, balance, and knee flexion/extension strength in older adults. PLoS One 13(6): e0198185, 2018.

3. Bohannon RW. Is it legitimate to characterize muscle strength using a limited number of measures? J Strength Cond Res 22(1): 166–73, 2008.

4. Bohannon RW. Dynamometer measurements of grip and knee extension strength: Are they indicative of overall limb and trunk muscle strength? Percept Mot Skills 108(2): 339–42, 2009.

5. Bohannon RW. Are hand-grip and knee extension strength reflective of a common construct? Percept Mot Skills 114(2): 514–8, 2012.

6. Bohannon RW. Grip strength: An indispensable biomarker for older adults. Clin Interv Aging 14: 1681–91, 2019.

7. Bohannon RW, Magasi SR, Bubela DJ, Wang YC, Gershon RC. Grip and knee extension muscle strength reflect a common construct among adults. Muscle and Nerve 46(4): 555–8, 2012.

8. Buckner SL, Dankel SJ, Bell ZW, Abe T, Loenneke JP. The association of handgrip strength and mortality: What does it tell us and what can we do with it? Rejuvenation Res 22(3): 230–4, 2019.

9. Buckner SL, Dankel SJ, Mouser JG, Mattocks KT, Jessee MB, Loenneke JP. Chasing the top quartile of cross-sectional data: Is it possible with resistance training? Med Hypotheses 108: 63–8, 2017.

10. Buckner SL, Jessee MB, Mattocks KT, Mouser JG, Counts BR, Dankel SJ, et al. Determining strength: A case for multiple methods of measurement. Sports Med 47(2): 193–5, 2017.

11. Buckner SL, Kuehne TE, Yitzchaki N, Zhu WG, Humphries MN, Loenneke JP. The generality of strength adaptation. J Trainology 8: 5–8, 2019.

12. Cress ME, Meyer M. Maximal voluntary and functional performance levels needed for independence in adults aged 65 to 97 years. Phys Ther 83(1): 37–48, 2003.

13. Cuoco A, Callahan DM, Sayers S, Frontera WR, Bean J, Fielding RA. Impact of muscle power and force on gait speed in disabled older men and women. Journals Gerontol Ser A Biol Sci Med Sci 59(11): 1200–6, 2004.

14. Dankel SJ, Loenneke JP, Loprinzi PD. Determining the importance of meeting muscle-strengthening activity guidelines: Is the behavior or the outcome of the behavior (strength) a more important determinant of all-cause mortality? Mayo Clin Proc 91(2): 166–74, 2016.

15. Dankel SJ, Loenneke JP, Loprinzi PD. Dose-dependent association between muscle-strengthening activities and all-cause mortality: Prospective cohort study among a national sample of adults in the USA. Arch Cardiovasc Dis 109(11): 626–33, 2016.

16. Dantas EHM, Vale RGS. GDLAM'S protocol of functional autonomy evaluation. Fit Perform J 3(3): 175–82, 2004.

17. Felicio DC, Pereira DS, Assumpção AM, de Jesus-Moraleida FR, de Queiroz BZ, da Silva JP, et al. Poor correlation

between handgrip strength and isokinetic performance of knee flexor and extensor muscles in community-dwelling elderly women. Geriatr Gerontol Int 14(1): 185–9, 2014.

18. Granacher U, Muehlbauer T, Gruber M. A qualitative review of balance and strength performance in healthy older adults: Impact for testing and training. J Aging Res 2012: 708905, 2012.

19. Harris-Love M, Benson K, Leasure E, Adams B, McIntosh V. The influence of upper and lower extremity strength on performance-based sarcopenia assessment tests. J Funct Morphol Kinesiol 3(4): 53, 2018.

20. Hopkins WG. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a P value. Sportscience 11: 16-20 (sportsci.org/2007/wghinf.htm), 2007.

21. Hopkins WG. Spreadsheets for analysis of validity and reliability. Sportscience 19: 36-42 (sportsci.org/2015/ValidRely.htm), 2015.

22. Hortobágyi T, Katch FI, LaChance PF. Interrelationships among various measures of upper body strength assessed by different contraction modes. Eur J Appl Physiol Occup Physiol 58(7): 749–55, 1989.

23. Jawan L, Adnan R, Sulaiman N, Ismail SI. Efficacy of handgrip strength in predicting total body strength among high performance athletes. Proc Int Colloq Sport Sci Exerc Eng Technol 29–38, 2014.

24. Kerksick CM, Mayhew JL, Grimstvedt ME, Greenwood M, Rasmussen CJ, Kreider RB. Factors that contribute to and account for strength and work capacity in a large cohort of recreationally trained adult healthy men with high- and low-strength levels. J Strength Cond Res 28(1246–1254), 2014.

25. Lee MR, Jung SM, Bang H, Kim HS, Kim YB. Association between muscle strength and type 2 diabetes mellitus in adults in Korea: Data from the Korea national health and nutrition examination survey (KNHANES) VI. Med 97(23): e10984, 2018.

26. Lee MR, Jung SM, Bang H, Kim HS, Kim YB. The association between muscular strength and depression in Korean adults: A cross-sectional analysis of the sixth Korea National Health and Nutrition Examination Survey (KNHANES VI) 2014. BMC Public Health 18(1): 1123, 2018.

27. Lee MR, Jung SM, Kim HS, Kim YB. Association of muscle strength with cardiovascular risk in Korean adults: Findings from the Korea National Health and Nutrition Examination Survey (KNHANES) VI to VII (2014-2016). Med 97(47): e13240, 2018.

28. Lima TR, Silva DAS, Kovaleski DF, González-Chica DA. The association between muscle strength and sociodemographic and lifestyle factors in adults and the younger segment of the older population in a city in the south of Brazil. Cien Saude Colet 23(11): 3811–20, 2018.

29. Martien S, Delecluse C, Boen F, Seghers J, Pelssers J, Van Hoecke AS, et al. Is knee extension strength a better predictor of functional performance than handgrip strength among older adults in three different settings? Arch Gerontol Geriatr 60(2): 252–8, 2015.

30. Nascimento MA, Januário RS, Gerage AM, Mayhew JL, Cheche Pina FL, Cyrino ES. Familiarization and reliability of one repetition maximum strength testing in older women. J Strength Cond Res 27(6): 1636–42, 2013.

31. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1–8, 2019.

32. Nunes JP, Cunha PM, Mayhew JL, Ribeiro AS, Sugihara Junior P, Fernandes RR, et al. Influence of handgrip stabilization during isokinetic knee strength assessment in older women. Percept Mot Skills 127(4): 671–83, 2020.

33. Nunes JP, Ribeiro AS, Silva AM, Schoenfeld BJ, dos Santos L, Cunha PM, et al. Improvements in phase angle are related with muscle quality index after resistance training in older women. J Aging Phys Act 27(4): 515–20, 2019.

34. Santos L, Ribeiro AS, Schoenfeld BJ, Nascimento MA, Tomeleri CM, Souza MF, et al. The improvement in walking speed induced by resistance training is associated with increased muscular strength but not skeletal muscle mass in older women. Eur J Sport Sci 17(4): 488–94, 2017.

35. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: Training considerations.

Sports Med 48(4): 765–85, 2018.

36. Verdijk LB, van Loon L, Meijer K, Savelberg HH. One-repetition maximum strength test represents a valid means to assess leg strength in vivo in humans. J Sports Sci 27(1): 59–68, 2009.