Published in final edited form as:

Exp Aging Res. 2019 ; 45(3): 282–292. doi:10.1080/0361073X.2019.1609145.

Psychometric Properties of Lower Extremity Strength Measurements Recorded in Community Settings in Independent Living Older Adults

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Abstract

Background: A uniaxial load cell device provides an alternative, easy and inexpensive way to quantify muscle strength in different settings outside the clinic and research labs. So, the purpose of the study was to examine the test-retest reliability and the construct validity of lower extremity strength performance using a uniaxial load cell device.

Methods: A total of 131 subjects (85% female, mean age 80 ± 8 years) were included for the validity aim, and a sample of 38 subjects were enrolled in the reliability testing (89% female, mean age 76 ± 7 years). For the strength measurements were assessed with a portable load cell for three consecutive trials. Test-retest reliability was assessed over two testing visits occurring one week apart. Spearman's rank correlation coefficient was used to test convergent validity with other mobility related measurements construct validity at baseline.

Results: Strength measurements showed good to excellent reliability in most of measured parameters with intraclass correlation coefficients range from 0.89 to 0.99 and were correlated with mobility measurements with Spearman rho range from 0.21 to 0.38.

Conclusion: The portable uni-axial load cell to measure lower extremity strength provides reliable measurements in community settings.

Keywords

Muscle strength; Independent living facilities; uniaxial load cell

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CONFLICTS OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest

INTRODUCTION

Aging results in reduced function in several body systems including cardiovascular, sensory, neuromuscular, and cognitive function. These factors have been related to reduced mobility and increased fall risk in older adults (Gangavati et al., 2011; Lord, 2006; Segev-Jacobovski et al., 2011). In particular, lower-extremity muscle weakness has been identified as a risk factor that contributes to mobility limitations and falls in older adults (Gill, Gahbauer, Murphy, Han, & Allore, 2012; Rubenstein, 2006). In addition, muscle strength is a critical component for performing activities of daily living safely and independently within their society and thereby avoiding falls (Hairi et al., 2010).

Give the importance of mobility for successful ageing, the assessment of muscle strength is important for identifying older adults who are at high risk of falling, and for developing exercise interventions to address any strength impairments. Reliable and valid assessment instruments are necessary to obtain consistent and repeatable measurements for muscle strength. The standard way to measure lower extremity muscle strength is using computerized isokinetic dynamometry (Stark, Walker, Phillips, Fejer, & Beck, 2011). However, the time demand, expense, and low portability are drawbacks that limit the application of computerized isokinetic dynamometry in independent living facilities. Another method used to assess strength is manual muscle testing. Although it is frequently used to measure muscle strength in the clinic, it lacks adequate psychometric properties, is prone to examiner's error, and is subject to a ceiling effect (Conable & Rosner, 2011; Jackson, Samuel Cheng, Russell Smith Jr, & Kolber, 2016). Handheld dynamometers have been used in different settings to objectively quantify muscle strength. Even though the portable handheld dynamometry has been proven to be accurate, valid, and reliable in different populations, it has some important limitations, such as difficulty in stabilizing the body part, and the reading is influenced by the strength of the examiner especially for larger muscles (Clarke, Ni Mhuirheartaigh, Walsh, Walsh, & Meldrum, 2011; Marmon, Pozzi, Alnahdi, & Zeni, 2013). Another alternative method that has been considered is the use of uniaxial load cells ; however they have yet to be tested in community-based settings (Alqahtani et al., 2017; Dura, Gianikellis, & Forner, 1996). A uniaxial load cell device may improve upon the above limitations to quantify muscle strength in people living in community settings, who may have difficulty getting transportation to research labs (McMurdo et al., 2011). In order to use this as an assessment tool, the method should demonstrate adequate reliability and validity. Therefore, the purpose of this study was to examine the test-retest reliability and validity of lower-extremity strength measurements, and to determine the minimal clinically important difference.

METHODS

Design and Subjects

This was an ancillary study of a cluster randomized clinical trial (RCT) that investigated the effect of two different group exercise programs on walking ability and self-reported function and disability (Brach et al., 2017). This study took place from April 2014 to May 2016. A subsample of 131 participants from the RCT were invited during their baseline assessment to take part in this study. For test-retest reliability, a subsample of 38 subjects

returned one week later to take part in a retest session. The time interval of one week was short enough to make sure that no real change has occurred, and long enough to minimize the effect of fatigue that may have occurred in the first testing. The construct validity of lower-extremity strength measurements with different mobility measurements was examined for all subjects at baseline. The minimal clinically important difference (MCID) was estimated using data from all subjects, using a distribution-based approach (Copay, Subach, Glassman, Polly, & Schuler, 2007). All subjects signed a consent form approved by the University of Pittsburgh Institutional Review Board prior to participation (IRB# REN15110236 / PRO14020565).

Inclusion and exclusion criteria followed that of the parent study. The inclusion criteria were: (1) 65 years of age or older; (2) a resident of a University of Pittsburgh Medical Center (UPMC) independent living facility (ILF), senior high rise, or a senior community center; (3) ability to ambulate independently within the household with or without a straight cane; and (4) gait speed greater than or equal to 0.60 m/s. Subjects were excluded if they had one or more of the following exclusion criteria: (1) non-English speaking; (2) impaired cognition, which is defined as the inability to follow two-step commands or understand the informed consent process; (3) plans to leave the area for an extended period of time over the next four months; (4) a progressive neuromuscular disorder such as Parkinson disease or multiple sclerosis; (5) any acute illness or medical condition that was not stable; or (6) an inappropriate response to the 6-Minute Walk Test (6MWT) (i.e. exercise heart rate ≥ 120 bpm, exercise systolic BP ≥ 220 or SPB >10 mmHg, or drop in diastolic BP ≥ 110 mmHg).

Lower Extremity Strength Measurement

A uni-axial load cell (Measurement Specialties XTC Series) was used to measure lower extremity strength. The load cell has a maximum capacity of 2225 N. The load cell was connected to an amplifier that displayed the instantaneous and maximum force exerted on the load cell. The load cell is arranged in series with straps (two cuffs), as can be seen in Figure 1, that fit around the limb on one end and a stable object on the other end.

Study Protocol

Subjects attended two testing visits for the test–retest reliability assessment with one week apart. The experimental study groups (two exercise groups in the parent study) from which they were selected was not controlled. Strength measurements included three maximum voluntary isometric contractions (MVIC) for knee extension, hip abduction, and ankle plantarflexion, in this order. All of the testing was done in the sitting position; details about the device positions for each muscle group have been published in Strength measurements included three maximum voluntary isometric contractions (MVIC) for hip abduction, knee extension and ankle plantarflexion as described in (Alqahtani et al., 2017). A standardized verbal encouragement, “one, two, three, and start!...PUSH!...PUSH!...PUSH!....and relax!”, were given to participants motivation to make sure that the maximum contraction was produced at every testing session. A thirty-second rest was provided between trials. The average of the three trials was used in the data analysis². All of the measurements were taken by a physical therapist. To standardize which leg was tested, the dominant foot was determined by asking the subjects about the foot that they would use to kick a ball

(Hoffman, Schrader, Applegate, & Koceja, 1998). Hip abductor strength was tested bilaterally due to the subject positioning.

In order to examine construct validity, strength measurements were collected for all subjects at baseline along with other mobility measures that were collected by investigators from the parent study. These measures included the Six-Minute Walk Test (6MWT) (Butland, Pang, Gross, Woodcock, & Geddes, 1982), 4-meter gait speed (Brach, Perera, Studenski, & Newman, 2008), Figure-of-8 Walk Test (F8WT) (Hess, Brach, Piva, & VanSwearingen, 2010), Short Physical Performance Battery (SPPB) (Guralnik et al., 1994), Gait Efficacy Scale (GES) (Newell, VanSwearingen, Hile, & Brach, 2012), and repeated chair-stands test (Lord, Murray, Chapman, Munro, & Tiedemann, 2002).

Statistical Analysis

Overview—Data were analyzed using SAS software version 9.4 (SAS Institute, Inc., Cary, NC). Strength data was inspected visually using histograms and descriptive statistics to examine the normality of the distribution. Descriptive statistics of subject demographic characteristics were reported. In this study, test was used to examine the existence of systematic bias (Bruton, Conway, & Holgate, 2000). The level of statistical significance was set at $\alpha = 0.05$ for all analyses.

Reliability—Test–retest reliability one week apart was estimated for lower extremity muscle strength. Intraclass correlation coefficients (ICC, model 3.1, two-way mixed-effects model) and 95% confidence intervals (95% CI) were calculated to examine the relative reliability. The ICC was defined as the ratio of between-subject variability to the total variability. The ICC index ranges from 0 to 1; values that are closer to 1 represent higher reliability.

Validity—The construct validity of the strength measurements was examined by calculating the correlation of strength measurements with the mobility measurements at the initial baseline assessment. The Shapiro-Wilk test revealed a non-normal distribution of the the strength data, hence the Spearman's rank correlation coefficients were used to examine the relationship between muscle strength measurements with the various mobility measurements: the 6MWT, gait speed, GES, F8WT, SPPB and SPPB balance, and repeated chair-stands test.

Minimal Clinically Important Difference (MCID)—Distribution-based measures of the MCID included the effect size and Standard Error of Measurement (SEM) for muscle strength measurements. The effect size (ES) estimate was based on the standard deviation of each outcome measurement for all subjects ($n=131$); a small ES was computed as $0.2 \times SD$, and a substantial ES was computed as $0.5 \times SD$. The SEM was calculated using the standard deviation (SD) and the ICC as follows: $(SEM = SD \sqrt{1 - ICC})$ (Copay et al., 2007). The SEM was calculated for the whole sample ($n=131$).

RESULTS

Demographic and clinical characteristics of the study sample are summarized in Table 1. As expected in this population, most of the participants were female. Co-morbid conditions were common. The reliability subsample was a few years younger than the whole sample, but otherwise similar in most characteristics.

Test–retest reliability

A Wilcoxon signed-rank test showed no significant difference between the means of the test and retest sessions across all strength measurements ($P > 0.05$), indicating no systematic bias was detected as shown in Table 2. Table 2 displays the ICC values for test–retest reliability for lower-extremity strength measurements using a uniaxial-load cell device. The ICCs after averaging three consecutive trials for hip abductors, knee extensors, and ankle plantarflexors were excellent (ICC= 0.95, 0.99, and 0.90, respectively). The output from the first trial showed lower ICC values but remained above 0.75 indicating excellent reliability as can be seen in Table 2.

Validity

The Spearman rank correlation coefficients between lower extremity strength and the different mobility measurements are shown in Table 3. The strongest correlations demonstrated that greater lower extremity strength was related to less time to complete the repeated chair-stand test with Spearman's rho ranging from -0.33 to -0.38 , $p < 0.01$. In addition, ankle plantarflexion strength had the highest correlation with the SPPB (Spearman's rho = 0.38 , $p < 0.01$). In general, greater lower extremity strength was related to better gait self-efficacy, and better performance in the F8WT, 6MWT, and gait speed tests.

Minimal Clinically Important Difference (MCID)

Table 4 details the distribution-based MCID values. The effect size estimates, which are based only on the baseline standard deviation, were similar for hip abduction and knee extension strength, and larger for the ankle plantarflexion. The SEM, which is based on the standard deviation and reliability coefficient, was twice as large for knee extension compared with hip abduction. The SEM for the ankle plantarflexion was four times higher than hip abduction and about two times greater than the knee extension. Although no previous studies have used the current device with older adults to quantify muscle strength, others used isokinetic dynamometry reported different values of SEM. For instance, de Carvallo, reported a SEM of 8 for knee extension strength in comparison to Morrison et al. (Morrison & Kaminski, 2007) who reported a SEM of 15 for ankle plantarflexors strength assessment, whereas SEM for hip abduction strength was estimated as 3.5 (Mentiplay et al., 2015).

DISCUSSION

Reliability

The strength values in the current study were consistent with published reference values from adults 70–79 years old that were obtained using a hand-held dynamometer (HHD)

(Andrews, Thomas, & Bohannon, 1996; Bohannon, n.d.; Jackson et al., 2016). Our results indicated excellent test-retest reliability for all lower extremity muscle strength groups. In addition, our study showed that a measurement from single trial would be enough to obtain an adequate reliability in strength measurements. Therefore, the uniaxial load cell appears to provide a reliable and inexpensive measure of muscle strength.

Validity

Lower extremity strength measurements in this study had the highest correlation with repeated chair stands time, reinforcing the repeated chair stands test as a measure of lower limb strength. However, the correlation in this study (Spearman rho = -0.33 to -0.38) was lower than findings from previous studies in which lower extremity strength explained about 40–48% of the variance in repeated chair stands performance (Lord et al., 2002; McCarthy, Horvat, Holtsberg, & Wisenbaker, 2004; Schenkman, Hughes, Samsa, & Studenski, 1996). In these previous studies, muscle strength groups were normalized for factors such as age, weight, and height, which could explain the higher correlation, that was clear when we normalized our data to these factors slightly improvement in the correlation coefficients was noticed (data not shown). Consistent with a previous finding (McCarthy et al., 2004), the ankle plantarflexors showed the strongest correlation with repeated chair stands time among the muscle groups, which may be explained by its important contribution in stabilizing the body in the upright standing position during each chair rise. The weak relationship in the current study, between muscle strength and the repeated chair stands test, implies that other factors are also of importance such as balance, sensorimotor, and psychological factors (Lord et al., 2002).

Ankle plantarflexor strength also had a moderate correlation with SPPB performance, which was greater than the correlations between SPPB and hip and knee strength. In addition to repeated-chair-stands performance, the SPPB includes a test of standing with a narrow base of support, which is partially determined by ankle strength. Therefore, ankle strength is a strong contributor to two of the three SPPB components. The strength of the correlation between lower extremity strength and the rest of the mobility measures was lower compared with the repeated chair stands. The determinants of performance for these other mobility measures would appear to rely more on several other physiological capabilities in addition to strength, such as cardiovascular endurance for the 6MWT, and balance and motor control for the F8WT.

Both knee extensors and hip abductors but not ankle plantarflexors had a significant but weak correlation with the time to complete the F8WT. The correlation was higher in stroke survivors and patients with total knee arthroplasty, in which researchers found a moderate correlation ($r = -0.46$ for knee extensors and -0.67 for hip abductors) between the F8WT and strength measures (Piva et al., 2011; Wong, Yam, & Ng, 2013). In agreement with previous findings we found a correlation of 0.24 between gait speed and knee extension strength, and a correlation of 0.22 for hip abduction strength (Bohannon, 1997; Uematsu et al., 2014). Giving the relationship of muscle strength to gait performance is modest at best (Brown, Sinacore, & Host, 1995). The type of relationship between gait speed and lower extremity strength has been demonstrated to be a non-linear relationship meaning some

physiological changes such as age-related loss of muscle mass may have more effects on gait speed in weak older adults than in healthy older adults (Buchner, Larson, Wagner, Koepsell, & de Lateur, 1996).

Minimal Clinically Important Difference

Knowledge about the MCID for lower extremity muscle strength could help to promote the use of the uniaxial-load cell in clinics, help clinicians to interpret the change that is important to patients, and help researchers in evaluating the clinical significance of an intervention. To the best of our knowledge there are no published studies that estimated the MCID of lower extremity strength using a uniaxial load cell device. An advantage of using a distribution-based approach is the ability to account for change beyond measurement random variation, compared to the anchor-based approach. However, a big drawback of using this approach is it doesn't address the patients' or subjects' perspective of clinically important change (Copay et al., 2007).

A limitation of the current study was that muscle strength testing was limited to three muscle groups, i.e. knee extensors, hip abductors, and ankle plantarflexors. Although these are important muscles for maintaining standing balance and walking, other muscle groups that have some contribution to walking could have been included, such as hip extensors, knee flexors, and ankle dorsiflexors. The reason for not including them is that older adults may not have tolerated a longer testing time, given that most of testing sessions were done after they finished testing from the parent study within the same day.

CONCLUSION

The uniaxial-load cell provides a feasible, reliable, and affordable method, that requires minimal training to administer, for testing lower extremity muscle strength in older adults in community settings. Using one trial could be enough to get excellent reliability of strength measurements by using the uniaxial-load cell device. By giving the aforementioned advantages of using the uniaxial-load cell device to quantify muscle strength may help investigators access understudied older populations living in independent living facilities, and will allow clinicians to examine objective measurements in real-life environments.

ACKNOWLEDGEMENTS

Research reported in this article was funded through a Patient-Centered Outcomes Research Institute (PCORI) Award (CE-1304–6301) and the Pittsburgh Older Americans Independence Center (NIA P30 AG024827). The statements in this article are solely the responsibility of the authors and do not necessarily represent the views of the Patient-Centered Outcomes Research Institute (PCORI), its Board of Governors or Methodology Committee. The authors gratefully acknowledge the support from the On the Move team and for the assistance in recruiting subjects for this study. We also thank staff and participants of the sites from which data has been collected

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Figure 1:

A load cell transducer and amplifier on the left. On the right the load cell is attached to subject's legs to measure seated hip abductor muscle strength.

Table 1:

Demographic and clinical characteristics of subjects

Variable	Validity Sample (n=131)	Reliability subsample (n=38)
Age, years (SD)	80.3 (7.7)	76.4 (6.5)
Female, n (%)	111 (85)	33 (87)
Race		
White n (%)	110 (84)	31 (82)
Married, n (%)	28 (21)	6 (16)
Education, ^a n (%)	70 (53)	18(47)
Chronic conditions		
Cardiac, n (%)	24 (18)	9 (24)
Musculoskeletal, n (%)	115 (88)	33 (87)
Visual/Hearing, n (%)	104 (79)	24 (63)
Diabetes, n (%)	24 (18)	13 (34)
Cancer, n (%)	28 (21)	8 (21)
Lung, n (%)	41 (31)	13 (34)
Total comorbidity		
> 3 conditions, n (%)	40(31)	16 (42)
< 3 conditions, n (%)	91(69)	22 (58)

^a defined as attending at least some college

Table 2:

Median and Interquartile Range of lower extremity isometric strength performance during test and retest, p-values from Wilcoxon signed ranks test, and reliability indicated by the intraclass correlation coefficient (ICC) and 95% confidence interval (n=38) for the average of 3 trials and the first trial (N=38).

Isometric Strength (N)	Test Median (IQR [*])	Retest Median (IQR)	p-value	ICC (95% CI) (3 trial average)	ICC (95% CI) (First trial)
Hip Abduction	170 (143–217)	170 (146–219)	0.35	0.99 (0.97–0.99)	0.95 (0.89–0.97)
Knee Extension	195 (166–237)	186 (172–247)	0.39	0.95 (0.90–0.97)	0.91 (0.85–0.96)
Ankle Plantarflexion	194 (150–223)	202 (158–233)	0.09	0.90 (0.81–0.95)	0.89 (0.81–0.94)

* IQR= interquartile range

Table 3:

Spearman rank correlation coefficients between lower extremity strength and the the Short Physical Performance Battery balance (SPPB), Gait Efficacy Scale (GES), Figure of 8 Walk Test (F8WT), Six-Minute Walk Test (6MWT), Gait Speed and Repeated Chair-rise Time (N=131).

Isometric Strength	SPPB	GES	F8WT	6MWT	Gait speed	Chair-rise time
Hip Abduction	0.29 **	0.28 **	- 0.25 **	0.29 **	0.22 *	- 0.33 **
Knee Extension	0.28 **	0.21 *	- 0.26 **	0.24 **	0.24 *	- 0.33 **
Ankle Plantarflexion	0.38 **	0.22 *	- 0.15	0.24 **	0.25 **	- 0.38 **

* indicates significant correlation coefficient $p < 0.05$.

** indicates significant correlation coefficient $p < 0.01$.

Table 4:

Distribution-based meaningful differences for lower extremity strength (n= 131)

Isometric Strength (N)	Small ES: 0.2 SD	Moderate ES: 0.5 SD	SEM
Hip Abduction	13.55	33.88	6.78
Knee Extension	12.77	31.93	14.28
Ankle Plantarflexion	17.75	44.38	28.07

ES: effect size, SD: baseline standard deviation, SEM: standard error of measurement