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Comparison of Handgrip to Leg Extension Strength for Predicting Slow Gait Speed in Older Adults

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Abstract

Background—The FNIH Sarcopenia Project developed evidence-based criteria for clinically relevant weakness based on handgrip strength (HG). Physical mobility relies primarily on actions of the lower extremity musculature, an comparison of HG to leg strength is necessary to justify the

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Drs. Fragala, Alley, Shardell, Harris, McLean, Kiel, Cawthon, Dam, Studenski and Dr. Kenny: intellectual content of the paper by conception and design; analysis and interpretation of data; and preparation of manuscript. Drs. Gudnason, Eiriksdottir, Koster, Newman, Siggeirdottir, Satterfield: acquisition and preparation of manuscript. Drs. Ferrucci, Guralnik, Kritchevsky, Vassileva: interpretation of data and preparation of manuscript.

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acceptability of strength assessment modality intended to inform a differential diagnosis of mobility disability.

Objectives—To compare the relative predictive power of HG and leg extension strength for predicting slow walking.

Methods—Leg strength, HG, and gait speed were measured in 6766 older men and women (aged 67–93 y) in data from the FNIH Sarcopenia Project. Strength cut-points associated with slow gait speed were developed using Classification and Regression Tree (CART) analyses and compared using ordinary least squares regression models.

Results—The cut-points of lower extremity strength associated with slow gait speed were 154.6 and 89.9 N-m for isometric and 94.5 and 62.28 N-m for isokinetic leg extension strength in men and women, respectively. Weakness defined by HG (OR = 1.99 to 4.33; c-statistic = 0.53 to 0.67) or leg strength (OR = 2.52 to 5.77; c-statistic = 0.61 to 0.66) strongly relate to the odds of having slow gait speed. Lower extremity strength and HG contributed 1 to 16 % and 3 to 17%, respectively, in the prediction of gait speed depending on sex and mode of strength assessment.

Conclusion—Muscle weakness of both the leg extensors and forearm flexors are related to slow gait speed. Leg extension strength is only a slightly better predictor of slow gait speed. Thus, both grip and leg extension strength appear to be suitable for screening for muscle weakness in a population of older adults.

Keywords

Sarcopenia; lower extremity function; walking speed

INTRODUCTION

Muscle weakness is a strong predictor of physical disability in older adults [1–6], but consensus for strength assessment modality and thresholds have been lacking. Recently, the Foundation of the National Institutes of Health (FNIH) Biomarkers Consortium Sarcopenia Project developed evidence-based criteria for clinically relevant weakness and low muscle mass in older persons [7]. Cut-points of strength were developed that distinguish muscle weakness associated with mobility impairment based on HG [8]. However, as physical mobility relies primarily on actions of the lower extremity musculature [9], an unbiased comparison of HG to lower extremity strength is necessary to justify the acceptability of strength assessment modality intended to inform a differential diagnosis of mobility disability.

Therefore, the purpose of this paper is to compare the relative predictive power of grip strength and leg extension strength to predict slow walking. We compared grip strength and two measures of lower extremity strength as predictors of gait speed, the primary indicator of mobility impairment within the FNIH Sarcopenia Project due to its strong associations with incident disability and mortality [7]

METHODS

Overview & Participants

We used individual participant data from two of the nine sets of cohorts (Table 1) that participated in the FNIH Sarcopenia Project [7]. **The AGES-REYKJAVIK cohort** consisted of 4,853 men and women aged 67–93 years enrolled in the Age Gene/Environment Susceptibility-Reykjavik Study (AGES-REYKJAVIK), an ongoing population-based study of Icelandic men and women, previously described [18]. **The Health ABC cohort** [19–21] consisted of 1,913 Medicare-eligible men and women aged 76–85 years who had complete data on the key variables at the 6^{th} annual examination [7].

Measures

Gait speed was measured in meters per second (m/s) as the time to walk a specific distance at a "usual pace." The Health ABC participants walked a 4-meter distance and the AGES-REYKJAVIK study participants walked a 6-meter distance, [21] then converted to 4-meter times using Guralnik formula [22].

Grip Strength was measured in kilograms (kg) using a hand-held dynamometer or a fixed chair (GoodStrength, Metitur, Palokka, Finland) as described previously [8]. The maximum value from either hand was used for analysis.

Leg Extension Strength was measured in Health ABC as peak torque achieved on an isokinetic (movement performed at a constant speed) dynamometer (model 125 AP, Kin-Com, Chattanooga, TN) at 60° per second. [19, 23]. In AGES-REYKJAVIK, highest maximal isometric (muscle contraction with no change in joint angle) of 3 attempts of dominant leg extension strength was measured on an adjustable computerized dynamometer on a fixed chair (GoodStrength, Metitur, Palokka, Finland) at a fixed knee angle of 60°[24].

Statistical Analysis

All descriptive participant statistics, including strength measures and gait speed, and analyses were stratified by sex. Because measures of lower extremity strength (isometric vs. isokinetic), differed between the two cohorts, analyses were stratified by cohort. Continuous associations between grip strength, leg strength, and gait speed were examined using Pearson correlation coefficients and Ordinary Least Squares (OLS) regression.

OLS regressions determined the increase in gait speed associated with a one standard deviation increase in grip or leg extension strength. Three unadjusted models and three models adjusted for age and BMI were fit to examine the relative contributions of grip and leg extension strength to walking speed, based on both the slope of the relationship (i.e., the coefficient) and the amount of variance explained (i.e., the R^2): Model 1 included grip strength only; model 2 included leg strength only; and model 3 included both grip and leg strength, in order to examine their independent associations with gait speed.

In order to compare participants who are classified as "weak" based on grip strength vs. lower extremity strength, we replicated the methods from the FNIH Sarcopenia in the two cohorts under study and derived cut-points in each cohort. Scatterplots and LOESS plots (nonparametric method for estimating regression surfaces) were used to examine the overall shape and identify potential nonlinearities in the relationship between strength and gait speed.

Classification and regression tree (CART) analysis [25] was performed to identify sample-specific grip and knee cut-points in the prediction of continuous gait speed. The CART approach has previously been used as a nonparametric statistical technique used to optimize concurrent validity to study of the association between strength and walking speed [8, 26–28]. Finally, logistic regression was used to compare weakness defined by grip strength or leg strength in the prediction of slow gaits speed (<0.8m/s) (as described previously)[7,8]. Similar to continuous analysis, three models were tested in order to examine the relative contributions of grip and leg strength to walking speed, based on both the strength of the relationship (i.e., the coefficient) and the accuracy of discrimination of the outcome (the c-statistic). Two sided P-values < 0.05 were considered statistically significant.

RESULTS

The AGES-REYKJAVIK sample was significantly younger, stronger, and had a greater proportion of women and white race compared to the Health ABC sample (table 1). The average gait speed was slower and the proportion that walked slowly was higher in AGES-REYKJAVIK compared to Health ABC cohort. Grip strengths for men and women, respectively, were higher in AGES-REYKJAVIK compared to Health ABC cohort. LOESS plots (not shown) did not suggest any clear trends in non-linearity or change points in the data. The simple correlations between handgrip strength and leg extension strength was $r = 0.57$ ($p < 0.001$) in men and $r = 0.51$ ($p < 0.001$) in women from the AGES-REYKJAVIK cohort, and $r = 0.40$ ($p < 0.001$) in men and $r = 0.44$ ($p < 0.001$) in women from Health ABC.

The single and combined associations between continuous HG and leg extension strength with gait speed in both cohorts are shown in Table 2. For AGES-REYKJAVIK, HG (model 1) and isometric leg strength (model 2) were each significantly associated with gait speed, and both contributed independently when included in the same model without adjusting for age and BMI (model 3). HG and isometric leg extension strength each explained about the 14.8–16.7 % variance in men and women and together explained more variance than either alone (19.0–21.5 %). When adjusted for age and BMI in AGES-REYKJAVIK, HG (Adjusted model 1) and isometric leg strength (Adjusted model 2) each remained significantly associated with gait speed, and both contributed independently when included in the same model (Adjusted model 3).

In men from Health ABC, both HG and isokinetic leg strength contributed significantly to gait speed individually and in combination in unadjusted models (table 2). However, in women from Health ABC, both HG and leg extension strength contributed to gait speed individually, but HG was no longer an independent predictor after conditioning on leg strength (model 3). HG explained only 4.6 % of the variance in walking speed in men and 1.4% in women while isokinetic leg extension strength explained 7.4% in men and 3.9% in women. HG was no longer an independent predictor after additional adjustment for age and BMI (Adjusted model 3) in both men and women.

Results from the CART analysis designed to identify weakness cut-points are shown in appendix. Based on these cut-points, 10.8% and 29.6% of men and 16.1% and 27.0% of women were classified as weak or "intermediate," respectively, by leg extension in the AGES sample and 30.5% of men and 26.0% of women were classified as weak by HG.

In men and women from AGES, weakness defined by grip strength (OR = 4.43 in men and OR = 3.92 in women) and weakness defined by (isometric) leg extension strength (OR = 5.77 in men and OR = 4.52 in women) were each strongly related to the odds of having slow gait speed (Table 3). Discriminatory ability to predict slow gait speed from strength was slightly higher when both grip and leg strength are combined (c-statistic = 0.69 – 0.71) compared to either measure alone (c-statistic for grip strength = 0.64–0.67; c-statistic for leg strength = 0.61).

In men and women from Health ABC (isokinetic leg extension strength), 29.2% of men and 38.0% of women were classified as weak by leg extension and 39.0% of men and 7.9% of women were classified as by HG

In men and women from Health ABC, weakness defined by grip strength (OR = 2.90 in men and OR = 1.99 in women) and weakness defined by leg extension (isokinetic) strength (OR = 3.92 in men and OR = 2.52 in women) were each strongly related to the odds of having slow gait speed (Table 3), Discriminatory ability to predict slow gait speed from grip strength was lower than in the AGES cohort, but was slightly higher when both grip and leg strength are combined (c-statistic = 0.62 – 0.71) compared to either measure alone (c-statistic for grip strength = 0.53–0.63; c-statistic for leg strength = 0.61–0.66). Inn women from the Health ABC cohort, weakness defined by grip strength was no longer significant after controlling for weakness defined by leg strength.

DISCUSSION

Analyses revealed that HG and leg extension strength generally explain similar magnitudes of variance in gait speed in a population with slower average walking speed. Previous studies have reported stronger associations between strength and function when strength is assessed on the corresponding muscle group [12, 13, 29]. However, our data in a large well-characterized cohort of older adults show very similar associations between grip and leg strength and gait speed.

Observed correlations between HG and isometric leg extension strength (r = 0.57 in men and r = 0.51 in women) were comparative to previous reports (r= 0.54 to 0.91) [14–17]. Similarly, our findings that muscular strength explained a significant portion of the variability in gait speed are also in agreement with previous studies [30–3233]. Explained variance of 17 to 20% in predicting gait speed from leg strength has previously been reported in another cohort of older adults [32] where a composite of multiple lower extremity strength measures were included in reported models [32]. Taken together, results reveal that multiple measures of strength slightly improves the ability to predict gait speed, but a single measure, as shown in the present study, significantly and perhaps adequately predicts gait speed.

The strength of the relationship between grip strength and gait speed and leg strength and gait speed was noticeably attenuated in a population with faster gait speed (Health ABC). In this cohort, HG and isokinetic leg extension strength were correlated, but somewhat less strongly. Previous reports have suggested that gait speed is more adversely affected by severe weakness and the relationship between strength and gait speed is weaker in stronger individuals [32].

While the relationship between strength and gait speed was arguably stronger in the population with a higher prevalence of slow walkers, different modes of leg extension strength measurement also may have contributed somewhat to the observed differences. After adjustment for age and BMI, (isometric) grip strength appeared to be almost as good as *isometric* leg strength in predicting gait speed in the AGES-REYKJAVIK cohort. However, *isokinetic* leg extension strength appeared to be somewhat stronger predictor of gait speed than (isometric) grip strength in the Health ABC cohort. Although, *isometric* and *isokinetic* leg extension strength have been previously shown to be correlated in older adults (r = 0.72–0.85) [15], we cannot compare in the present cohorts. The distinct methodologies used to evaluate lower extremity muscle strength in our selected analytic sample highlight the lack of consensus in a uniform and widely accepted measure of lower extremity muscle strength.

Although our results demonstrate that muscular strength is an important contributor to gait speed, strength only accounts for a relatively small portion (less than 10%) of the total variance leaving the majority of variance to be explained by other contributing factors. Additionally, in older adults, reaction time, balance, proprioception, vision, and cognition have all been attributed for variations in gait speed [35–38]. In addition, strength assessments in the present study may not reflect the musculature that may impede human gait. However, previous investigators have reported moderate to high correlations (r = 0.66 to 0.80) between leg extension strength and other measures of lower extremity strength in older adults [32].

Despite the reported relationship between muscle strength and gait speed, a categorical classification of weakness that is associated with gait speed may be useful clinically. Previous reports have suggested that gait speed is more adversely affected by severe weakness and the relationship between strength and gait speed is weaker in stronger individuals [32]. Additionally, previous reports have classified older adults as weak (“dynapenic”) based on different low isokinetic strength (lowest strength tertile) found that 24% of weak had a walking disability [41].

Grip strength cut-points derived through CART modeling in AGES and Health ABC were generally different than those for previously reported in the FNIH Consortium pooled sample [8]. Thus, cut-points derived here should not be confused with the larger pooled sample cut-points previously reported [8] and should be used with caution, given that both cohorts are relatively strong, high-functioning populations.

Never-the-less, muscle weakness defined by HG or leg extension strength cut-points derived from CART analysis were each strongly related to the odds of having slow gait speed in both cohorts. Additionally, discriminatory ability to predict slow gait speed from strength was slightly higher when both grip and leg strength were combined compared to either measure alone and relationships were modestly attenuated when both weakness measured by grip and leg strength were included in the same model. This suggests that there are both independent and shared associations between leg and HG measures of weakness and slow walking speed.

Despite the strengths of the study, the results should be interpreted within the context of potential limitations. Although the analysis samples were somewhat large and diverse, they may not be representative of older adults in general; individuals with mobility impairments were potentially underrepresented and age between the cohorts used in this analysis are disparate. Causal relationships between strength and gait speed cannot be inferred and data cannot portray how changes in strength may affect gait speed over time. Finally, the threshold of lower extremity muscle weakness at which gait speed is negatively impacted is yet to be determined. Further work is needed to examine how these associations change over time and how treatments and interventions may benefit weak or slow older adults.

CONCLUSIONS

HG may be an adequate measure to predict physical function in clinical settings and provides support for selecting grip strength as a measure of strength in developing a clinical definition of sarcopenia. Leg extension strength is only a slightly better predictor of slow gait speed. Thus, results support performing a preliminary strength assessment by the more feasible HG dynamometer, while more intricate measures of muscle specific lower extremity strength may be used for follow-up testing. Alternatively, since gait measures are relatively easy to perform in the office setting, and since strength measures only explain a small percent of the variance in gait speed, it may be more useful to directly measure gait speed. Slow gait speed might then prompt a search for contributing causes such as muscle weakness. Nevertheless, these results will be useful in the development of consensus diagnostic criteria for sarcopenia from a muscle specific perspective.

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Appendix

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Table 1

Descriptive Characteristics of Participants in Two Cohort Studies.

	AGES-REYKJAVIK		Health ABC		P-value
	N	Mean (SD) or %	N	Mean(SD) or %	
Men	2082		919		
Age (y)		76.6 (5.4)		78.4 (2.8)	<0.001
BMI (kg/m^2)		26.85 (3.79)		27.04 (3.87)	0.21
Gait speed (m/s)		0.97 (0.21)		1.16 (0.23)	<0.001
Gait speed <0.8m/s		20.0%		5.7%	<0.001
Grip strength (kg)		39.1 (9.5)		37.1 (8.4)	<0.001
Leg extension strength (N-m)		168.0 (48.0)†		111.3 (29.5)‡	--
Women	2771		994		
Age (y)		76.4 (5.6)		78.0 (2.8)	<0.001
BMI (kg/m^2)		27.18 (4.79)		27.33 (5.42)	0.44
Gait speed (m/s)		0.91 (0.20)		1.06 (0.22)	<0.001
Gait speed <0.8m/s		28.4%		12.2%	<0.001
Grip strength (kg)		23.6 (5.9)		23.1 (5.8)	0.020
Leg extension strength (N-m)		96.1 (30.0)†		69.7 (20.8)‡	--

†Isometric measurement

‡Isokinetic measurement

P-value indicates differences by population. Isometric leg extension strength is shown for the AGES-REYKJAVIK cohort and isokinetic strength is shown for the Health ABC cohort. Leg extension strength could not be compared because of different measurement approaches.

Table 2

a & b.Associations Between Strength Measures and Gait Speed: Ordinary Least Squares Regression (unadjusted) a) AGES-REYKJAVIK study; b) Health ABC study.

a.

AGES-REYKJAVIK	**Standardized regression coefficients**			**Adjusted** Standardized regression coefficients**		
Men(N=2,082)	**Model 1**	**Model 2**	**Model 3**	**Adjusted Model 1**	**Adjusted Model 2**	**Adjusted Model 3**
Grip (kg)	0.389 *		0.251 *	0.273 *		0.162 *
Isometric leg extension (N-m)		0.384 *	0.240 *		0.311 *	0.234 *
R^2 ***	0.151	0.148	0.190	0.061	0.078	0.094
Women (N=2,771)						
Grip (kg)	0.399 *		0.256 *	0.276 *		0.181 *
Isometric leg extension (N-m)		0.408 *	0.276 *		0.299 *	0.223 *
R^2	0.159	0.167	0.215	0.064	0.076	0.098

b.

Health ABC (Y6)	**Standardized regression coefficients**			**Adjusted** Standardized regression coefficients**		
Men (N=919)	**Model 1**	**Model 2**	**Model 3**	**Adjusted Model 1**	**Adjusted Model 2**	**Adjusted Model 3**
Grip (kg)	0.214 *		0.125 *	0.193 *		0.106
Isokinetic leg extension (N-m)		0.272 *	0.222 *		0.282 *	0.244 *
R^2 ***	0.046	0.074	0.087	0.035	0.073	0.082
Women (N=994)						
Grip (kg)	0.120 *		0.043	0.147 *		0.065
Isokinetic leg extension (N-m)		0.193 *	0.174 *		0.241 *	0.214 *
R^2	0.014	0.037	0.039	0.020	0.051	0.054

* $p<0.001$

** Adjusted for age and BMI. Standardization based on multiplying the regression coefficient by the standard deviation of its corresponding predictor and dividing by the standard deviation of gait speed.

*** Partial R^2 for adjusted model (i.e., R^2 for grip and/or leg strength, conditioned on age and BMI being in the model)

* p<0.001

** Adjusted for age and BMI. Standardization based on multiplying the regression coefficient by the standard deviation of its corresponding predictor and dividing by the standard deviation of gait speed.

** Partial R^2 for adjusted model (i.e., R^2 for grip and/or leg strength, conditioned on age and BMI)

Model 1 tested grip strength alone, model 2 tested leg strength alone and model 3 tested both measures simultaneously. Standardized coefficients indicate gait speed increases for every one standard deviation increase in grip or leg extension strength. * indicates p<0.001

Table 3

Association Between Strength and Slow Gait Speed: Logistic Regression

	AGES-REYKJAVIK (N=2082)			Health ABC (N=919)		
Men	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Weak grip	4.43 (3.54–5.55)		3.43 (2.68–4.32)	2.90 (1.62–5.18)		2.16 (1.18–3.96)
Weak leg		5.77 (4.32–7.71)	3.59 (2.63–4.89)		3.92 (2.21–6.97)	3.21 (1.77–5.82)
C-statistic	0.67	0.61	0.71	0.63	0.66	0.71
Women	AGES-REYKJAVIK (N=2771)			Health ABC (N=994)		
Weak grip	3.92 (3.27–4.70)		3.08 (2.55–3.73)	1.99 (1.11–3.58)		1.38 (0.75–2.53)
Weak leg		4.52 (3.66–5.58)	3.30 (2.64–4.12)		2.52 (1.71–3.71)	2.40 (1.61–3.58)
C-statistic	0.64	0.61	0.69	0.53	0.61	0.62

Model 1 tested grip strength alone, model 2 tested leg strength alone and model 3 tested both measures simultaneously.

Table

Leg Strength Cut-points Derived From Classification and Regression Tree Analysis (CART)

	Leg strength cut-point (N-m)[†]	**% in group**	**Leg strength cut-point (N-m)**[‡]	**% in group**
Men	AGES-REYKJAVIK (N=2082)		Health ABC (N=919)	
Weak	<110.4	10.8	<94.5	29.2
Intermediate	110.4–154.5	29.6		
Normal	>=154.6	59.6	>=94.5	61.0
Women	AGES-REYKJAVIK (N=2771)		Health ABC (N=994)	
Weak	<66.5	16.1	<62.3	38.0
Intermediate	66.5–89.7	27.0		
Normal	>=89.8	56.9	>=62.3	62.0

[†] Isometric measurement

[‡] Isokinetic measurement

Table

Grip Strength Cut-points Derived From Classification and Regression Tree Analysis (CART)

	Grip strength cut-point (kg)	% in group	Grip strength cut-point (kg)	% in group
Men	AGES-REYKJAVIK (N=2082)		Health ABC (N=919)	
Weak	<34.4	30.5	<34.3	39.0
Intermediate	34.4–45.6	44.6		
Normal	>45.6	24.8	>=34.3	61.0
Women	AGES-REYKJAVIK (N=2771)		Health ABC (N=994)	
Weak	<19.9	26.0	<15.8	7.9
Intermediate	19.9–23.9	25.8		
Normal	>=23.9	48.2	>=15.8	92.2

Table

a-d. Comparison of Weakness Defined by Grip Strength vs. Leg Strength

a.				
AGES-REYKJAVIK Men		**Grip Strength**		
		Not Weak	**Weak**	**Total**
Leg Strength	Not Weak	1380	477	1857
	Weak	62	163	225
	Total	1442	640	2082

b.				
AGES-REYKJAVIK Women		**Grip Strength**		
		Not Weak	**Weak**	**Total**
Leg Strength	Not Weak	1850	476	2326
	Weak	201	244	445
	Total	2051	720	2771

c.				
Health ABC		**Grip Strength**		
		Not Weak	**Weak**	**Total**
Leg Strength	Not Weak	449	202	651
	Weak	112	156	268
	Total	561	358	919

d.				
Health ABC		**Grip Strength**		
		Not Weak	**Weak**	**Total**
Leg Strength	Not Weak	601	15	616
	Weak	315	63	378
	Total	916	78	994

1543/2082 (74.1%) were classified as the same

477/2082 (22.9%) were classified as weak by grip, but not weak by leg strength

62/2082 (3.0%) were classified as weak by leg, but not weak by grip strength

2094/2771 (75.6%) were classified as the same

476/2771 (17.2%) were classified as weak by grip, but not weak by leg strength

201/2771 (7.2%) were classified as weak by leg, but not weak by grip strength

605/919 (65.8%) were classified as the same

202/919 (22.0%) were classified as weak by grip, but not weak by leg strength

112/919 (12.2%) were classified as weak by leg, but not weak by grip strength

664/994 (66.8%) were classified as the same

15/994 (1.5%) were classified as weak by grip, but not weak by leg strength

315/994 (31.7%) were classified as weak by leg, but not weak by grip strength