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Framework for a short muscle function battery using electronic handgrip dynamometry and accelerometry in older adults

Ryan McGrath[a,b,c,d,e,*], **Grant R. Tomkinson**[d], **Sarah Andrew**[a,b], **Joshua Batesole**[a,b], **Chloe Carling**[a], **Bryan K. Christensen**[b], **Samantha FitzSimmons**[a,b], **Halli Heimbuch**[a,b], **Tyler Hoang**[b], **Donald Jurivich**[c], **Jacob Kieser**[a,b], **Kelly Knoll**[a,b], **Peyton Lahr**[a,b], **Matthew Langford**[a,b], **Michaela Mastrud**[a], **Megan Orr**[f], **Yeong Rhee**[b], **Kyle J. Hackney**[b]

[a]Healthy Aging North Dakota (HAND), North Dakota State University, Fargo, ND, USA

[b]Department of Health, Nutrition, and Exercise Sciences, North Dakota State University, Fargo, ND, USA,

[c]Department of Geriatrics, University of North Dakota, Grand Forks, ND, USA

[d]Alliance for Research in Exercise, Nutrition, and Activity (ARENA), Allied Health and Human Performance, University of South Australia, Adelaide, South Australia, Australia

[e]Fargo VA Healthcare System, Fargo, ND, USA

[f]Department of Statistics, North Dakota State University, Fargo, ND, USA

Abstract

Background: Electronic handgrip dynamometry and accelerometry enables novel opportunities to collect additional attributes of muscle function beyond just maximal strength, but some muscle function attributes may already be related, which may warrant discerning these attributes into a short muscle function battery (SMFB).

Objectives: We sought to determine the multivariate relationships between maximal strength, asymmetry, submaximal control, rate of force development, bimanual coordination, fatigability, and contractile steadiness in older adults.

[*]Corresponding author at: North Dakota State University, 1805 NDSU Research Park Dr. N., Fargo, ND 58102. ryan.mcgrath@ndsu.edu (R. McGrath).

Declaration of competing interest

The authors declared no conflicts of interest in the paper.

CRediT authorship contribution statement

Ryan McGrath: Writing – original draft, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Grant R. Tomkinson:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **Sarah Andrew:** Writing – review & editing, Methodology. **Joshua Batesole:** Writing – review & editing, Methodology. **Chloe Carling:** Writing – review & editing, Methodology. **Bryan K. Christensen:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **Samantha FitzSimmons:** Writing – review & editing, Methodology. **Halli Heimbuch:** Writing – review & editing, Methodology. **Tyler Hoang:** Writing – review & editing, Methodology. **Donald Jurivich:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **Jacob Kieser:** Writing – review & editing, Methodology. **Kelly Knoll:** Writing – review & editing, Methodology. **Peyton Lahr:** Writing – review & editing, Methodology. **Matthew Langford:** Writing – review & editing, Methodology. **Michaela Mastrud:** Writing – review & editing, Methodology. **Megan Orr:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **Yeong Rhee:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **Kyle J. Hackney:** Writing – review & editing, Project administration, Methodology, Formal analysis.

Design: A cross-sectional design was used for this investigation.

Setting: Laboratory.

Participants: The analytic sample included 121 generally healthy older adults aged 70.7 ± 4.7 years.

Measurements: Electronic handgrip dynamometry and accelerometry measured strength, asymmetry, submaximal control, rate of force development, bimanual coordination, fatigability, and contractile steadiness. The handgrip variables were standardized before they were included in a factor analysis. Factors with eigenvalues > 1.0 were kept. Items within a factor with a loading | > 0.30| were similarly retained.

Results: There were 3 factors retained with eigenvalues of 1.88, 1.56, and 1.10. The first factor (functional strength), which explained 39.9 % of the variance, included strength, submaximal control, and rate of force development. Factor 2 (lateral function), which explained 35.8 % of the variance, included asymmetry and bimanual coordination. The third factor (muscle endurance), which explained 24.3 % of the variance, included fatigability and contractile steadiness.

Conclusions: Our findings suggest the surfacing of themes in the additional muscle function measures, thereby providing framework for a SMFB. More research is needed for electronic handgrip dynamometry and accelerometry derived muscle function on health before consideration of implementation in clinical practice.

Keywords

Aging; Geriatrics; Muscle strength; Muscle strength dynamometer; Muscle Weakness

1. Introduction

Handgrip strength is a convenient and reliable measure of strength capacity that generalizes to muscle function [1,2]. Guidelines for handgrip strength protocols recommend a hydraulic handgrip dynamometer be used to collect the highest recorded grip force observed on a needle gauge from a single hand to determine maximal strength [3]. However, the prognostic utility of handgrip strength has undergone scrutiny for being an incomplete measure of muscle function because it only measures maximal force from a single hand [4]. These limitations in measurement may challenge clinical conversations between healthcare providers and patients regarding the specificity of strength capacity as a health risk factor given the multitude of adverse health outcomes linked to low handgrip strength [5]. Alternative muscle function assessments such as knee extension strength (or muscle power) are related to handgrip strength [6], robustly correlated with physical performance tasks [7], and could be a better predictor of mortality relative to muscle strength [8]. Yet, the use of knee extension strength may necessitate complex and expensive equipment that may not be inclusive of wide-ranging older adult functional abilities, which may compromise use of knee extension strength in clinical settings [2]. The body systems driving poor muscle function are multivariable and poorly operationalized by a single muscle attribute [9]. Therefore, new methods and equipment to feasibly assess additional muscle function attributes should be sought.

Electronic handgrip dynamometry and accelerometry (Fig. 1) enable a more detailed assessment of muscle function attributes beyond strength capacity such as submaximal control, rate of force development, fatigability, and contractile steadiness [5]. Grip force curves are observed on a computer monitor in real-time during tasks, and accelerometers, which can be placed on electronic handgrip dynamometers, collect the magnitude of neuromuscular tremoring during each gripping task. These new technologies and methods may not yet be ready for clinical use because of healthcare provider training, patient learning, clinical time, data processing, and restricted external energy sources (e.g., battery, plug-in), but as these technologies and research use evolves, this new approach to evaluating muscle function may uncover early deficits that are otherwise unidentified in current handgrip strength protocols. Such discoveries may advance the prognostic utility of muscle function through incorporating measures of underlying mechanisms that may drive the age-related motor changes that elevate risk for morbidity, functional limitations, and early all-cause mortality [5].

Poor physical performance, which succeeds deficits in muscle function, is assessed individually (e.g., gait speed, timed-up-and-go), and with multiple tests as part of a short physical performance battery (SPPB) [2,10]. Despite the promise for electronic handgrip dynamometry and accelerometry in feasibly collecting multiple functional attributes, a battery comprising these individual assessments may elevate the comprehensiveness of these techniques for assessing muscle function. The purpose of this study was to determine the multivariate relationships between strength, asymmetry, submaximal control, rate of force development, bimanual coordination, fatigability, and contractile steadiness as measured by electronic handgrip dynamometry and accelerometry in older adults. Although handgrip strength is measured across the lifespan [11], such measures are regarded as a health biomarker during aging [12], and the SPPB is considered an assessment tool for older adults [13]. Identifying the multivariate relationships between these attributes may provide a framework for the development of a short muscle function battery (SMFB).

2. Methods

2.1. Participants

A cross-sectional design was used for this investigation. Empirical power was estimated by simulation, using data from previous work [14]. Electronic handgrip dynamometry and accelerometry derived strength, asymmetry, submaximal control, bimanual coordination, fatigability, and contractile steadiness were standardized to have a mean of 0 and variance of 1. The covariance matrix was subsequently obtained. We then simulated these measures from the multivariate normal distribution using this covariance matrix for various sample sizes 1000 times to determine the required sample size to have at least 80 % power. Thereafter, we conducted a multivariate analysis and simulated the binary outcome of slow gait speed (< 0.8 m/s) [15], which was selected because it represents poor physical performance as the next step in the disabling process after low muscle function [2]. We then determined the proportion of the 1000 samples with a significant association between the handgrip tasks and slowness for the empirical power. Our simulation revealed that if 20 % of participants have slow gait speed [15], we will have 80 % power with 110 participants.

Adults aged at least 65-years were eligible. Flyers, campus listservs, institutional research registries, and word-of-mouth resources were used for recruitment. Persons undergoing treatment for cancer (excluding minor skin cancer); living with a neurological-related condition (e.g., stroke, Parkinson's disease) or dementia; not ready to engage in physical activity as determined by the PAR-*Q*+ [16]; lacking the ability to walk or extend and curl the leg at the knee without severe pain or limitations, and unable to squeeze a handgrip dynamometer on both hands due to severe pain, advanced arthritis, or a surgical procedure were excluded. Persons interested in our study contacted a trained interviewer to complete an eligibility questionnaire. Of the 137 persons completing the eligibility questionnaire, $n = 12$ were excluded for not meeting study criteria, and $n = 1$ was eligible but withdrew before consent for personal reasons. All participants provided written informed consent and the North Dakota State University Institutional Review Board approved protocols.

2.2. Measures

2.2.1. Descriptive characteristics: Participants completed a brief descriptive questionnaire and self-reported age, sex, hand dominance, and perceived health. Standing height and body mass were collected with a Seca 286 measuring station (Seca; Chino, CA). Body mass index was calculated as kg/m^2.

2.2.2. Handgrip tasks: Biopac SS25LA handgrip dynamometers (Biopac Systems; Goleta, CA) were used for handgrip testing, which have been validated to collect 0–90 kg of grip force [17]. These dynamometers were calibrated and connected with Biopac Student Lab Basic System Acquisition software for data collections and processing [18]. Guidelines for collecting handgrip strength were used to inform our protocols [3]. Participants sat in a stable chair with their feet flat on the floor, back against the back rest, and forearms on the arm rests of the chair with wrists in a neutral position (i.e., thumb facing upward). Trained interviewers explained each procedure before handgrip testing occurred, including with a visual demonstration and verbal encouragement during task performance as appropriate. The order of hands first tested was block randomized. Given the multitude of grip force tasks participants were asked to complete, two trials of each grip force task were completed on each hand with a minute of rest between measures. Although there are different recommended test ordering procedures for mitigating fatigue and optimizing human performance [19], we chose a standardized order for our grip force tasks to similarly reduced fatigue and enhance human performance, but also to accommodate any learning effects from completing certain grip force tasks. The following order was incorporated: 1) maximal strength, 2) submaximal control, 3) rate of force development, 4) bimanual coordination, and 5) fatigability.

During maximal strength measurements, participants squeezed the dynamometer with maximal effort, exhaling while squeezing for a few seconds, and then they released muscle tension on the dynamometer. The highest recorded value was included as strength capacity [3]. Moreover, the highest recorded value on each hand was included in the asymmetry calculation: *(highest handgrip strength (kg) / highest handgrip strength on the opposite hand (kg))* [20].

A 25 % submaximal value was determined from the highest recorded handgrip strength on each hand, and participants were asked to maintain the 25 % submaximal target grip force for 10-seconds [21]. The computer monitor displayed the grip force generated in real-time to help participants gauge their grip force and adjust accordingly. A coefficient of variation was calculated over the middle eight seconds and the lowest coefficient of variation was included in the analyses [21].

Rate of force development is often ascertained as the ability to generate maximal muscle fiber activation as quickly as possible [22]. To evaluate rate of force development, participants were instructed to squeeze the dynamometer, “as fast and as hard as possible for about a second ” to place an emphasis on muscle contraction speed. Rate of force development was calculated as peak force normalized to time, and the highest performing value was included in the analyses [22].

Symmetric, in-phase tasks of the upper extremities that have simultaneous mirror-image spatial and temporal movements of equal force are the simplest in complexity for assessing bimanual coordination [23]. Therefore, we placed a handgrip dynamometer in each of the participant’s hands and asked them to squeeze with maximal effort, exhaling while squeezing, at the same time before releasing. For each trial, the recorded handgrip strength values on each hand were used to calculate bimanual coordination ratio: *(higher handgrip strength (kg) / lower handgrip strength (kg))*. As such, the bimanual coordination ratio closest to 1.0 was included in the analyses [9].

For examining fatigability, participants were instructed to squeeze the dynamometer with maximal effort for as long as possible. Grip force was collected starting when the dynamometer was first squeezed until the participant voluntarily released or fatigued to 50 % of the maximal handgrip strength on each hand [24]. The 50 % fatigue threshold was blinded to participants. Fatigability index quantified the aligning grip force curve: *(1 – (real area / ideal area)) x 100 %* [25]. The lowest fatigability index, which signifies lower fatigability, was included in the analysis.

An ActiGraph GT3X-BT triaxial accelerometer (ActiGraph; Pensacola, FL) was attached to the top of the dynamometer for measuring contractile steadiness during all handgrip tasks. ActiLife software (Acti-Graph) initialized accelerometers at 60 Hz and processed data. The specific start and end times (in seconds) for every handgrip measurement were recorded and corresponded with the time stamps from the electronic handgrip dynamometry. Data were stored in 1-second epochs. The average of the mean vector magnitudes from each handgrip task was included in the analyses. Participants with any missing handgrip data were excluded ($n = 3$).

2.2.3. Statistical analysis: All analyses were performed with SAS 9.4 software (SAS; Cary, NC). Pearson correlations examined the relationships of the strength, asymmetry, submaximal control, rate of force development, bimanual coordination, fatigability, and contractile steadiness measurements. An alpha level of 0.05 was used for the Pearson correlation analyses.

The handgrip measures included in the analyses were then standardized to have a mean of 0 and variance of 1 because they are measured on different scales. A factor analysis using varimax rotation was conducted on the standardized handgrip values. Briefly, a factor analysis simplifies a set of related variables for examining the underlying dimensions that the variables may have in common [26]. Factors summarize the covariation among observed and partition variables into sets that generally covary more strongly together than with other variables [27]. In compatibility with the Kaiser-Guttman criteria, components with eigenvalues > 1.0 were retained [28]. Specific handgrip tasks with a loading of | > 0.30|, which is reflective of the threshold for a moderate correlation [26], were likewise retained to indicate which variables were better associated with each individual factor.

3. Results

Table 1 shows the descriptive characteristics of the participants. Overall, the 121 participants were aged 70.7 ± 4.7 years, and 66.9 % were female. The correlations of the handgrip measurements in the SMFB are presented in Table 2. Strength was significantly correlated with submaximal control ($r = -0.22$; $p = 0.01$), rate of force development ($r = 0.64$; $p < 0.01$), and contractile steadiness ($r = 0.23$; $p < 0.01$), while asymmetry was significantly correlated with bimanual coordination ($r = 0.59$; $p < 0.01$).

Fig. 2 displays a scree plot for the factor analysis. Factors 1 (functional strength), 2 (bilateral function), and 3 (muscle endurance) were retained because they had eigenvalues of 1.88, 1.56, and 1.10, respectively. Table 3 presents factor loadings for the SMFB using electronic handgrip dynamometry and accelerometry. The first factor (functional strength), which explained 39.9 % of the variance, contained strength, submaximal control, and rate of force development. The second factor (lateral function) contained asymmetry and bimanual coordination, explaining 35.8 % of the variance. The third factor (muscle endurance), which explained 24.3 % of the variance, contained fatigability and contractile steadiness.

4. Discussion

The overarching findings of this investigation revealed differential multivariate relationships between the muscle function attributes collected from electronic handgrip dynamometry and accelerometry in older adults. Specifically, strength, submaximal control, and rate of force development loaded to Factor 1 (functional strength), asymmetry and bimanual coordination loaded to Factor 2 (lateral function), and fatigability and contractile steadiness loaded to Factor 3 (muscle endurance). Our findings provide a framework for a possible SMFB, using electronic handgrip dynamometry and accelerometry. A SMFB could be useful for more comprehensively assessing muscle function with several different tests in clinical practice, similar to how the SPPB classifies poor physical performance. Muscle function attributes within a possible SMFB could also be used to better predict future adverse health outcomes, extrapolate criterion- (e.g., cut-points) and norm-referenced standards (e.g., percentiles), and provide precision for interventions aiming to restore muscle function.

Although muscle strength and rate of force development are distinct attributes of muscle function, these attributes are nonetheless strongly and positively related, and peak strength

is part of the rate of force development calculation [22]. Resistance training interventions promoting strength and rate of force development have been shown to be effective in improving these attributes regardless of age, training type, and duration; however, these neuromuscular parameters should be examined independently [29], thereby suggesting a need for a muscle function battery examining both attributes within a component. Submaximal control is an indicator of neuromuscular outcomes [30,31] and maximal strength is needed to calculate the submaximal force target for this grip task.

Asymmetric strength of the limbs has implications for bilateral tasks [32], as unilateral limb performance is positively linked with bilateral performance [33]. Our investigation also calculated strength asymmetry and bimanual coordination as ratios, which may further elucidate why these muscle function attributes loaded within the same factor. Tremoring is a neuromuscular condition that can occur across the body, but is most commonly observed in the hands [34]. Isometric tremoring can be induced when muscles fatigue [34]. As such, it is unsurprising that fatigability and contractile steadiness loaded the same a factor. However, future work may examine if fatigability and contractile steadiness load to the same factor without creating muscle fatigue.

Although each factor identified in our investigation (functional strength, lateral function, muscle endurance) may have helped to distinguish the muscle function aspects we examined, the purpose and utility of measuring the muscle function attributes within our SMFB framework, or individually, may vary. For example, muscle force control is linked to the neuromuscular system [35]. Neuromuscular control may decline during aging, particularly when lower intensity muscle contractions involve elevated cognitive characteristics [36], which may have implications for cognitive impairment. Moreover, muscle strength and power are aspects of muscle function [37], but the rate of muscle force development is similarly connected to muscle power [22]. As such, the rate of force development may have utility for powerpenia [38], while strength may have predictive value for sarcopenia (Factor 1, functional strength) [39]. Strength asymmetry and bilateral deficit increase during aging [40,41], and while asymmetry may precede strength as a less severe type of muscle function limitation [42], aspects in Factor 2 (lateral function) may have implications for age-related musculoskeletal and neuromuscular health conditions. Muscle endurance (Factor 3) could be influential for executing the repetitive tasks involved in basic self-care and could be vulnerable to deterioration when age-related chronic conditions are present [43]. Fatigue and tremoring are hallmark characteristics of neurodegenerative conditions such as Parkinson’s disease [44], and fatiguability may help to quantify challenging to measure constructs such as resilience [45,46].

Electronic handgrip dynamometry and accelerometry enable feasible and novel opportunities to collect additional muscle function attributes beyond strength capacity. Although strength, asymmetry, submaximal control, rate of force development, bimanual coordination, fatigability, and contractile steadiness individually contribute to how muscles function, individual assessments of these muscle function attributes may lack comprehensiveness, and each aspect is uniquely associated with different health outcomes [5]. Our findings offer a framework for a SMFB to objectively measure multiple muscle function attributes, but it should be acknowledged that strength factors into each aspect

in some regard. Nonetheless, more research is needed to examine electronic handgrip dynamometry and accelerometry derived muscle function, including the creation of a SMFB given recent innovations in tools and methods. Testing such battery framework for predicting deficits in physical performance, basic self-care limitations, frailty, and other age-related health conditions (e.g., cognitive impairment) may help in supporting implementation in clinical settings.

Some limitations and notes should be listed. We elected not to calculate the rate of force development with shorter, segmented time intervals because the measurement effect was small for our approach. Other methods may exist for determining each aspect of muscle function we examined with electronic handgrip dynamometry and accelerometry. Participants were asked to complete several handgrip tasks, which may have led to misunderstandings of directions in some cases; however, multiple trials were collected for each grip task to help mitigate such misunderstandings. Shifts in hand lateralization could not be accounted for in our experimental design. We slightly oversampled regarding our power analysis to account for any missing data and errors the pilot data used to estimate the sample size. Our handgrip measures were standardized to avoid differences in scaling, which elevated factor comparability and variable equality in the analysis; however, loss of the original scaling through standardization may limit interpretability of our findings in some regards [47]. Most of our sample were generally healthy, which may threaten the generalizability of our findings to older adult populations with poorer health status.

5. Conclusions

Our findings provide framework for a SMFB with electronic handgrip dynamometry and accelerometry. Specifically, strength, submaximal control, and rate of force development loaded to Factor 1 (functional strength), asymmetry and bimanual coordination loaded to Factor 2 (lateral function), and fatigability and contractile steadiness loaded to Factor 3 (muscle endurance). Electronic handgrip dynamometry and accelerometry shows promise to feasibly and more comprehensively assess muscle function. However, more research is needed to examine association patterns before implementation in clinical practice.

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Fig. 1.
Electronic Handgrip Dynamometry and Accelerometry.

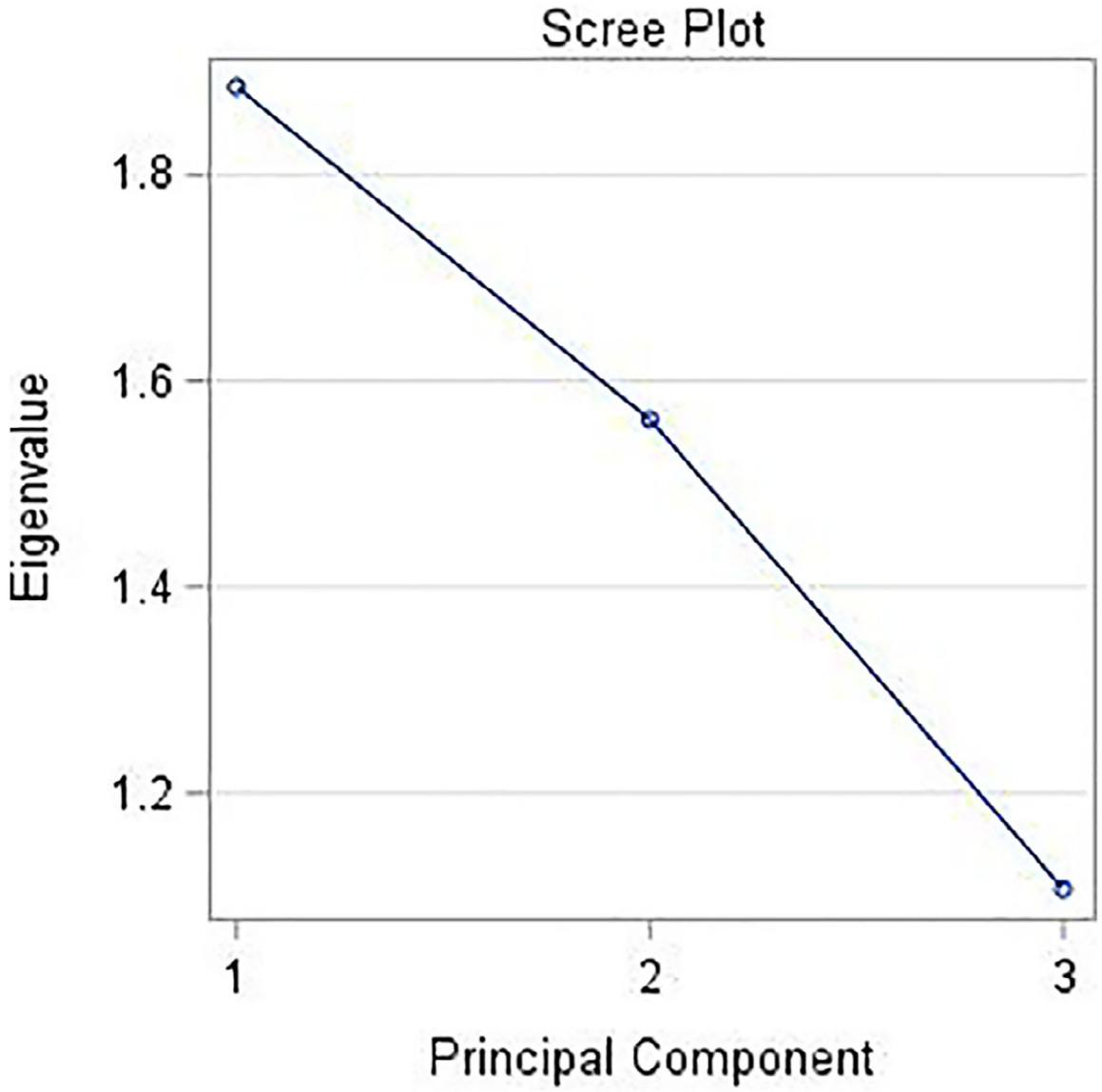

Fig. 2.
Scree Plot of Eigenvalues.

Table 1

Descriptive characteristics of the participants.

	***n* = 121**
Age (years)	70.7 ± 4.7
Female (n (%))	81 (66.9)
Right Hand Dominant (n (%))	110 (90.9)
Body Mass Index (kg/m^2)	28.9 ± 6.2
Self-Rated Health (n (%))	
Excellent	20 (16.5)
Very Good	67 (55.4)
Good	33 (27.3)
Fair	1 (0.8)
Poor	0 (0.0)
Maximal Strength (kg)	18.6 ± 6.9
Asymmetry Ratio	1.1 ± 0.1
Submaximal Control (CV)	6.0 ± 5.1
Rate of Force Development (Δforce/Δtime)	44.4 ± 24.9
Bimanual Coordination Ratio	1.1 ± 0.1
Fatigability Index (%)	34.0 ± 12.7
Contractile Steadiness (VM)	14.5 ± 11.2

Note: Results are presented as mean ± standard deviation or frequency (percentage) as indicated. CV = coefficient of variation; VM = vector magnitude.

Table 2

Correlations of the handgrip measurements included in the short muscle function battery.

	Strength	Asymmetry	Submaximal Control	RFD	Bimanual Coordination	Fatigability	Contractile Steadiness
Strength	-	$r = -0.11$; $p = 0.22$	$r = -0.22$; $p = 0.01$	$r = 0.64$; $p < 0.01$	$r = -0.06$; $p = 0.46$	$r = 0.07$; $p = 0.43$	$r = 0.23$; $p < 0.01$
Asymmetry	-	-	$r = 0.09$; 0 = 0.27	$r = 0.01$; $p = 0.90$	$r = 0.59$; $p < 0.01$	$r = -0.03$; $p = 0.73$	$r = -0.07$; $p = 0.43$
Submaximal Control	-	-	-	$r = -0.15$; $p = 0.09$	$r = 0.10$; $p = 0.24$	$r = 0.01$; $p = 0.92$	$r = -0.01$; $p = 0.90$
RFD	-	-	-	-	$r = 0.03$; $p = 0.66$	$r = 0.16$; $p = 0.06$	$r = 0.05$; $p = 0.53$
Bimanual Coordination	-	-	-	-	-	$r = -0.10$; $p = 0.25$	$r = -0.02$; $p = 0.79$
Fatigability	-	-	-	-	-	-	$r = -0.07$; $p = 0.39$
Contractile Steadiness	-	-	-	-	-	-	-

Note : RFD = rate of force development.

Table 3

Factor loadings for the short muscle function battery.

	Factor 1	Factor 2	Factor 3
Strength	0.88*	−0.04	−0.10
Asymmetry	−0.06	0.87*	0.04
Submaximal Control	−0.38*	0.19	0.06
Rate of Force Development	0.85*	0.12	0.16
Bimanual Coordination	−0.02	0.88*	−0.07
Fatigability	0.22	−0.09	0.75*
Contractile Steadiness	0.28	−0.07	−0.69*
Variance Explained	39.9 %	35.8 %	24.3 %

Note: Factor 1 = functional strength; Factor 2 = lateral function; Factor 3 = muscle endurance.

*significant factor loading (| > 0.30|).