PM R 11 (2019) 372-378

www.pmrjournal.org

Original Research

A Single Trial May Be Used for Measuring Muscle Strength With Dynamometers in Individuals With Stroke: A Cross-Sectional Study

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Abstract

Background: The mean of 3 trials is commonly employed to report measures of muscle strength after a stroke. However, consistent and reliable results have been found for single trial dynamometric measures of grip, pinch, and trunk strength in individuals with stroke. Nevertheless, no studies were found that investigated whether only a single trial could be used for the assessment of the strength of both the upper and lower limb muscles.
Objective: To determine the best scoring method (one vs the means of 2 or 3 trials) to measure the strength of the upper and lower limb muscles in individuals with sub-acute and chronic stroke.
Design: Cross-sectional observational study.
Setting: Research laboratory, participants' homes, and community-based settings.
Participants: Fifty-five individuals at the sub-acute (mean age: 61 $\pm$ 13 years; 3.7 $\pm$ 0.7 months poststroke) and 59 at the chronic poststroke phases (mean age: 57 $\pm$ 130 years; 90 $\pm$ 71 months poststroke).
Main Outcome Measurements: Bilateral maximum isometric strength measures of the shoulder, elbow, and wrist flexors/extensors; shoulder abductors; hip, knee, and ankle flexors/extensors; and hip abductors were obtained with a hand-held dynamometer.
Methods: After familiarization, 3 trials of maximal isometric strength were obtained for all evaluated muscle groups. One-way analysis of variance was used to compare the results obtained with the first vs the means of 2 and 3 trials for all the assessed muscle groups.
Results: The values provided by the different scoring methods were similar for all evaluated muscle groups in individuals with sub-acute ($.68 \le P \le .99$) and chronic ($.69 \le P \le .99$) stroke.
Conclusions: A single trial, after familiarization, may be used for measuring the strength of the upper and lower limb muscles with hand-held dynamometers in individuals with sub-acute and chronic stroke. This increases the clinical applicability of hand-held dynamometers for strength measurement, as it reduces the assessment burden placed on the participants and therapists.
Level of Evidence: III

Introduction

Muscle strength is commonly evaluated in individuals with stroke, because muscle weakness is associated with activity limitations after stroke [1]. Among the available instruments for the assessment of strength, the hand-held dynamometer is considered a practical standard instrument [2]. This device is portable, so it may be used within clinical settings, is easy to use, provides objective measures of strength of various muscle groups, and is sensitive for detecting changes over time [2-4]. In addition, it provides valid and reliable measures of strength in individuals with sub-acute and chronic stroke [2-6].

According to 2 systematic reviews that investigated the methods used to measure the strength of the upper and lower limb muscles with dynamometers after stroke, the number of employed trials ranged from 1 to 9 [3,4]. However, most of the included studies used the mean of 3 trials [3,4]. The choice of using the mean of 3 trials in

First published online by Elsevier on behalf of the American Academy of Physical Medicine and Rehabilitation, August 20, 2018

https://dx.doi.org/10.1016/j.pmrj.2018.08.377

Table 1
Positioning, stabilization, and device application

Muscle group	Participant's position	Position of the segment/joint	Stabilization done by the examiner	Location of force application by the examiner
Shoulder flexors/ extensors	Supine	Shoulder flexed to 90°, elbow extended, forearm and wrist in neutral	None	Proximal to the elbow over the flexor/extensor surface of the arm
Shoulder abductors	Supine	Shoulder abducted to 45°, elbow extended, forearm and wrist in neutral	Anterior region of the shoulder	Proximal to the elbow on the lateral surface of the arm
Elbow flexors/extensors	Supine	Shoulder, forearm, and wrist in neutral position, elbow flexed to 90°, and fingers flexed	Anterior region of the shoulder	Proximal to the wrist on the radial and ulnar border of the forearm
Wrist flexors/extensors	Supine	Shoulder, forearm, and wrist in neutral position, elbow flexed to 90°, and fingers flexed	Distal forearm	Palmar and dorsal region of the closed hand
Hip flexors/extensors	Supine	Hip and knee flexed to 90°	None	Distal and anterior/posterior aspect of the thigh
Hip abductors	Supine	Knee extended and hip in neutral	None	Distal and lateral aspect of the thigh
Knee flexors/extensors	Sitting	Hip and knee flexed to 90°	Distal and anterior aspect of the thigh	Distal and anterior/posterior aspect of the leg
Ankle dorsiflexors/ plantar flexors	Supine	Hip and knee extended and ankle in neutral position	Distal and anterior aspect of the leg	Proximal to metatarsophalangeal joints on the dorsal/plantar surfaces

the majority of the studies included in these reviews [3,4] may be explained by the regression toward the mean phenomenon. According to this phenomenon, extreme high scores indicate substantial positive errors, whereas extreme low ones may show substantial negative errors, originating from random sources [7]. However, in a second measure, these sources of errors would probably not be exactly the same [7]. Thus, the error component of an extreme score is likely to be less extreme when a second measure is taken [7]. Therefore, both very high and very low scores are expected to be closer or to regress, toward the mean [7]. Hence, the mean of 3 trials is commonly employed, in an attempt to reduce random errors.

Although most studies reported the mean of 3 trials, Faria et al [6] and Aguiar et al [5] reported that only a single trial was needed to provide consistent and reliable measures of grip, pinch, and trunk strength in individuals with stroke. However, to our knowledge, no studies have evaluated whether a single trial would also be appropriate for measuring the strength of the major muscle groups of the upper and lower limbs with dynamometers in individuals with stroke.

The use of a single trial may facilitate the clinical applicability and feasibility of hand-held dynamometers, by reducing the duration of the assessment and avoiding possible effects of muscular and general fatigue, lack of attention, and discomfort. This is especially relevant for individuals with stroke, who commonly have symptoms of fatigue [8]. Therefore, the aim of this study was to determine the best scoring method (one vs the means of 2 and 3 trials) to measure the strength of the upper and lower limb muscles in individuals with sub-acute and chronic stroke.

Methods

Participants

This cross-sectional observational study was approved by the institutional ethical review board (#0492.0.203.000-10) and was carried out in a research laboratory, participants' homes, and community-based settings. Individuals with stroke were recruited from the general community by screening outpatient clinics, research group lists, and contacting physical therapists. The inclusion criteria were as follows: clinical diagnosis of stroke (time since the onset of stroke between 3 and 6 months [sub-acute phase] or more than 6 months [chronic phase]) and ≥ 20 years of age. Exclusion criteria were cognitive impairments, as determined by cut-off values on the Mini-Mental State Examination (illiterate, 13 points; elementary and middle school, 18 points; and high-school, 26 points) [9], inability to understand verbal commands [10], pain, and/or other non-stroke-related conditions. Individuals were included even if they could

Table 2
Familiarization procedures

Steps	Description
1	Participants, body segments, and place of application of the dynamometer were standardized (Table 1).
2	Passive movement of the body segment to be tested was performed by the examiner in the direction of muscle contraction. For example, for the assessment of shoulder flexors, the examiner performed passive shoulder flexion.
3	One submaximal isometric contraction was performed, to ensure that the participants understood the correct muscle group to activate.

not activate some muscle groups and, thus, could not perform all the strength assessments.

All participants were informed about the aims of the study and provided written consent, prior to data collection. Demographic and clinical data were assessed by experienced physiotherapists for characterization purposes and included age, sex, body mass, height, paretic side, time since the onset of stroke, and motor function. Upper and lower limb motor impairment was assessed by the motor function section of the Fugl-Meyer assessment scale, which has shown adequate measurement properties in individuals with stroke [11,12]. Upper limb motor impairments were classified as mild (50-65 points), moderate (30-49 points), and severe (<30 points) [13], whereas lower limb impairments were classified as mild (>29 points), moderate (23-29 points), moderately severe (18-22 points), and severe (<17 points) [11].

The GPower software was used to determine the sample size, considering a medium effect size (f = 0.25), a power of 0.90, and an α of 0.05. The required sample would be 36 individuals for each subgroup (individuals at sub-acute and chronic poststroke stages). Some participants could not activate some muscle groups; thus, not all muscle groups were measured. To ensure that each muscle group would be measured in at least 36 participants, more individuals were recruited.

Outcome Measures

Bilateral measures of isometric strength (kgf) of the following upper and lower limb muscle groups were obtained: shoulder flexors/extensors and abductors; elbow flexors/extensors; wrist flexors/extensors; hip flexors/extensors and abductors; knee flexors/extensors; and ankle dorsiflexors/plantar flexors. These measures were obtained with a hand-held digital dynamometer (MicroFET 2; Hoggan Health Industries, Salt Lake City, UT), which is considered a practical standard method for the assessment of isometric strength [2]. Adequate measurement properties for the assessment of strength of the upper and lower limb muscles of individuals with stroke with hand-held dynamometer has been reported [2–6].

Procedures

The data were collected by a trained physical therapist, who had experience with muscle strength

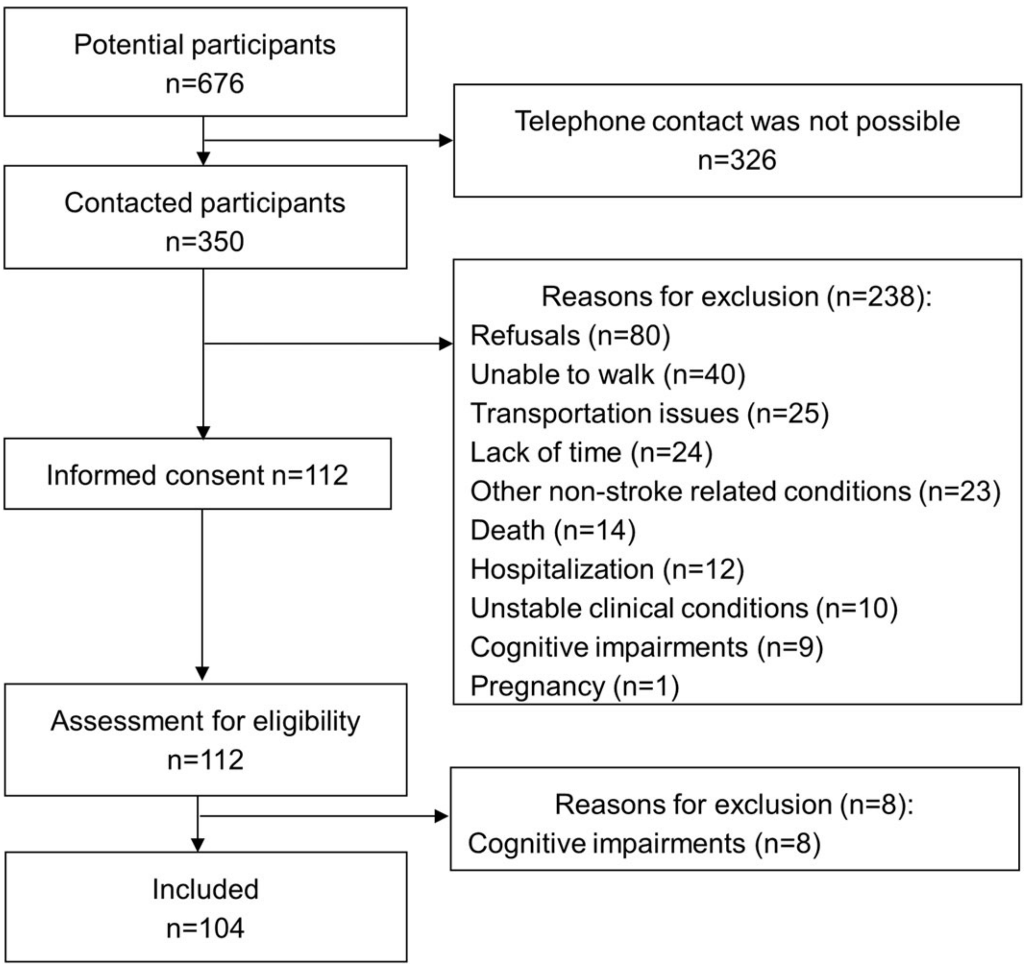

Figure 1. Flow diagram through the study.

measurement. The training of the physical therapist comprised repeated practice of the strength assessment procedures with healthy individuals, before starting collecting data for the present study. After eligibility criteria evaluation and collection of the clinical and demographical data, measures of strength were obtained. Participants' and segment positions, as well as the placement of the dynamometer and stabilization procedures were standardized (Table 1). First, the participants performed 1 submaximal isometric contraction, for familiarization purposes (Table 2), followed by three 5-second trials of maximal isometric strength of all evaluated muscle groups. A 20-second rest interval was provided between the trials. If the examiner recognized any compensatory movements by the participants, the trial was excluded, and a new measurement was obtained and registered. The examiner provided verbal encouragements during all assessments, as follows: "One, two, three, go! Force, force, force, force, force! Relax." The strength measurements were performed always in the same order. The limbs were alternately assessed, starting with the nonparetic side followed by the paretic one, to ensure that the participants understood the correct muscle group to activate.

Statistical Analyses

Descriptive statistics and tests for normality (Shapiro-Wilk) were calculated for all measures. One-way analysis of variance was used to compare the results obtained with the first vs the means of 2 and 3 trials for all the assessed muscle groups. All analyses were performed using the SPSS software version 25 (SPSS Inc, Chicago, IL) at a significance level of 5%.

Results

From a list of approximately 676 individuals, 326 could not be contacted (Figure 1). One hundred four individuals with stroke were included, 55 at the sub-acute phase (mean age, 61 $\pm$ 13 years; time poststroke, 3.7 $\pm$ 0.7 months) and 59 at the chronic phase (mean age, 57 $\pm$ 13 years; time poststroke, 90 $\pm$ 71 months). Their clinical and demographic characteristics are described in Table 3.

The descriptive data and the analysis of variance results are given in Tables 4 and 5. The values provided by the different scoring methods were similar for all evaluated muscle groups for both individuals with sub-acute ($.68 \le P \le .99$) and chronic ($.69 \le P \le .99$) stroke.

Discussion

The present study aimed at determining the best scoring method (first vs the means of 2 and 3 trials) to measure the strength of the upper and lower limb muscles in individuals with sub-acute and chronic stroke. The results demonstrated that, for the following 14 investigated muscle groups (shoulder flexors/extensors and abductors, elbow flexors/extensors, wrist flexors/extensors, hip flexors/extensors and abductors, knee flexors/extensors, and ankle dorsiflexors/plantar flexors), similar results were found between the measures obtained with a single trial and the means of 2 and 3 trials, for individuals at both sub-acute and chronic phases. Therefore, only a single trial, after a simple familiarization procedure (Table 2), may be used to evaluate the strength of the upper and lower limb muscles with hand-held dynamometers. This will optimize the time spent on assessments within both clinical and research settings.

The effect of the reliability of an instrument on the regression toward the mean phenomenon might explain the results of the present study. The reliability of an instrument has an impact on the extent to which the regression toward the mean effect will be present [7]. An instrument with adequate reliability will contain less error; thus, the results of the measurement should produce a score close to the true score [7]. Consequently, there is less chance for the regression toward the mean phenomenon to occur [7]. Because hand-held dynamometers have shown to provide reliable measures of strength of the upper and lower limb muscles of individuals with

Table 3
Participants' characteristics

Characteristics	Sub-acute stroke *n* = 55	Chronic stroke *n* = 59
Age, y, mean (SD); range [min-max]	60.7 (12.9); [29-85]	57.8 (13.8); [30-86]
Time since stroke, mo, mean (SD); range [min-max]	3.7 (0.7); [3-5]	90.9 (71.3); [7-370]
Body mass index, mean (SD); range [min-max]	24.7 (4.3); [14.9-36.7]	27.1 (4.9); [17.3-38.6]
Sex, n (%)		
Men	29 (53)	29 (49)
Paretic side, n (%)		
Right	28 (51)	30 (51)
Type of stroke, n (%)		
Ischemic	50 (91)	42 (71)
Hemorrhagic	4 (7)	8 (14)
Ischemic and hemorrhagic	1 (2)	4 (7)
Unknown	–	5 (8)
Upper limb motor impairments,* n (%)		
Mild (50-65)	38 (69)	32 (56)
Moderate (30-49)	2 (4)	12 (21)
Severe (<30)	15 (27)	13 (23)
Lower limb motor impairments,* n (%)		
Mild (>29)	33 (61)	26 (44)
Moderate (23-28)	7 (13)	19 (32)
Moderately severe (18-22)	3 (6)	8 (14)
Severe (<17)	11 (20)	6 (10)

SD = standard deviation.
*Fugl-Meyer scale scores [11,13].

Table 4
Strength measures (kgf) of all evaluated muscle groups for individuals with sub-acute stroke

Muscular groups (n)	First trial	Mean of 2 trials	Mean of 3 trials	*P* values
Nonparetic side				
Wrist flexors (55)	8.69 ± 2.30	8.44 ± 2.11	8.33 ± 2.06	.68
Wrist extensors (54)	7.57 ± 2.95	7.37 ± 2.81	7.24 ± 2.65	.82
Elbow flexors (53)	15.96 ± 5.92	15.72 ± 5.76	15.58 ± 5.70	.94
Elbow extensors (54)	10.84 ± 3.72	10.88 ± 3.68	10.74 ± 3.64	.98
Shoulder flexors (53)	12.63 ± 5.08	12.54 ± 5.01	12.49 ± 5.06	.99
Shoulder extensors (48)	14.69 ± 5.90	14.63 ± 5.76	14.57 ± 5.65	.99
Shoulder abductors (50)	9.94 ± 3.67	9.79 ± 3.58	9.68 ± 3.51	.94
Hip flexors (49)	8.31 ± 3.99	8.10 ± 3.72	8.02 ± 3.67	.93
Hip extensors (49)	10.70 ± 3.51	10.95 ± 3.46	11.06 ± 3.43	.87
Hip abductors (51)	9.34 ± 3.36	9.17 ± 3.27	9.03 ± 3.19	.89
Knee flexors (46)	8.33 ± 3.27	8.19 ± 3.248	8.06 ± 3.28	.93
Knee extensors (46)	11.17 ± 4.03	11.12 ± 3.96	10.99 ± 3.90	.98
Ankle plantar flexors (52)	9.42 ± 3.84	9.33 ± 3.84	9.22 ± 3.77	.96
Ankle dorsiflexors (50)	6.85 ± 2.75	6.73 ± 2.87	6.58 ± 2.85	.89
Paretic side				
Wrist flexors (41)	7.57 ± 2.95	7.37 ± 2.81	7.24 ± 2.65	.87
Wrist extensors (40)	7.72 ± 3.37	7.67 ± 3.35	7.64 ± 3.30	.99
Elbow flexors (42)	12.91 ± 6.33	12.89 ± 6.12	12.85 ± 6.20	.99
Elbow extensors (46)	8.87 ± 4.64	8.94 ± 4.61	8.87 ± 4.56	.99
Shoulder flexors (39)	12.11 ± 5.69	12.18 ± 5.55	12.08 ± 5.56	.99
Shoulder extensors (39)	14.45 ± 6.59	14.46 ± 6.66	14.46 ± 6.63	.99
Shoulder abductors (39)	8.55 ± 4.10	8.48 ± 3.96	8.49 ± 3.96	.99
Hip flexors (46)	7.41 ± 3.60	7.16 ± 3.48	7.07 ± 3.46	.89
Hip extensors (46)	10.48 ± 4.22	10.68 ± 4.10	10.68 ± 4.04	.96
Hip abductors (47)	8.36 ± 3.76	8.29 ± 3.41	8.35 ± 3.32	.99
Knee flexors (43)	6.71 ± 3.56	6.74 ± 3.46	6.74 ± 3.43	.99
Knee extensors (46)	9.77 ± 4.70	9.68 ± 4.61	9.69 ± 4.54	.99
Ankle plantar flexors (45)	8.66 ± 4.27	8.60 ± 4.06	8.51 ± 4.10	.99
Ankle dorsiflexors (44)	5.68 ± 2.43	5.71 ± 2.48	5.80 ± 2.46	.97

Values are mean ± standard deviation of strength measures and the results of the analysis of variance regarding the comparisons between the different scoring methods for the strength of the upper and lower limb muscles, assessed with a hand-held dynamometer.

stroke (0.58 ≤ correlation coefficient ≤ 0.99) [3-6], this may justify the findings; that is, similar values were provided by different scoring methods.

Previous studies that investigated whether dynamometry strength measures based upon various numbers of trials were statistically different, found similar results for the following muscle groups: grip; pulp-to-pulp, palmar, and lateral pinch; and trunk flexors/extensors, lateral flexors, and rotators of individuals with sub-acute (.92 ≤ *P* ≤ .99) [5] and chronic (.85 ≤ *P* ≤ .99) [6] stroke. In addition, Coldham et al reported that only a single trial of grip strength, measured with a dynamometer, in healthy individuals and in individuals who had undergone orthopedic surgery, is as reliable as the mean and the best value of 3 trials [14]. Recent studies also compared measures of strength of the upper and lower limb muscles obtained with a single trial vs the means of 2 and 3 trials (shoulder flexors/extensors and abductors; elbow flexors/extensors; wrist flexors/extensors; grip; pulp-to-pulp, palmar, and lateral pinch; hip flexors/extensors and abductors; knee flexors/extensors; and ankle dorsiflexors/plantar flexors) of individuals with sub-acute and chronic stroke, but measured with the Modified Sphygmomanometer Test [15–17]. They found that only a single trial, after familiarization, provided reliable strength measures for individuals with sub-acute (.87 ≤ *P* ≤ .99) [15] and chronic (.83 ≤ *P* ≤ .99) [16,17] stroke. The results of the present study corroborate previous findings, in which no significant differences between the measures were found when different numbers of trials were considered for the assessment of strength of the upper and lower limb muscles in individuals with sub-acute and chronic stroke.

The present findings are also similar to those reported for other outcomes in healthy and individuals with stroke. Faria et al investigated whether the use of a single trial, the means of 2 and 3 trials, and the best and the worst values of 3 trials affected the scores of 7 perfomance-based tests in individuals with chronic stroke [18]. These tests included comfortable and maximal gait speeds, comfortable and maximal stair ascent and descent cadences, as well as the timed "up and go" test [18]. They also found similar results for all scoring methods (.34 ≤ *P* ≤ .99) [18], indicating that only a single trial was necessary to provide reliable measures for the assessment of all evaluated performance-based tests [18]. Pinheiro et al also compared different scoring methods (first trial, the means of 3, of the first 2 and of the last 2 trials, and the highest of 3 trials) for the evaluation of lower

Table 5
Strength measures (kgf) of all evaluated muscle groups for individuals with chronic stroke

Muscular groups (n)	First trial	Mean of 2 trials	Mean of 3 trials	*P* values
Nonparetic side				
Wrist flexors (56)	7.51 ± 3.40	7.21 ± 3.13	7.00 ± 3.05	.69
Wrist extensors (56)	6.79 ± 3.30	6.58 ± 3.22	6.50 ± 3.23	.89
Elbow flexors (56)	14.03 ± 5.74	13.62 ± 5.52	13.46 ± 5.31	.86
Elbow extensors (56)	10.56 ± 4.50	10.34 ± 4.35	10.21 ± 4.27	.91
Shoulder flexors (56)	11.51 ± 5.07	11.49 ± 5.05	11.41 ± 5.09	.99
Shoulder extensors (56)	14.95 ± 6.99	15.03 ± 7.25	15.04 ± 7.22	.99
Shoulder abductors (56)	8.96 ± 4.19	8.75 ± 3.92	8.58 ± 3.81	.88
Hip flexors (57)	8.26 ± 3.89	8.05 ± 3.77	7.98 ± 3.70	.92
Hip extensors (55)	15.17 ± 5.84	15.21 ± 5.67	15.13 ± 5.61	.99
Hip abductors (55)	12.33 ± 5.07	12.12 ± 4.97	12.21 ± 5.02	.98
Knee flexors (55)	9.63 ± 4.41	9.48 ± 4.31	9.41 ± 4.24	.97
Knee extensors (54)	17.16 ± 7.92	16.71 ± 7.74	16.73 ± 7.74	.95
Ankle plantar flexors (55)	15.24 ± 5.49	15.14 ± 5.35	15.07 ± 5.32	.99
Ankle dorsiflexors (55)	9.79 ± 3.79	9.73 ± 3.70	9.56 ± 3.62	.95
Paretic side				
Wrist flexors (45)	5.15 ± 2.57	5.07 ± 2.53	5.00 ± 2.46	.96
Wrist extensors (44)	4.35 ± 3.04	4.35 ± 2.99	4.29 ± 2.96	.99
Elbow flexors (52)	9.76 ± 5.07	9.71 ± 5.04	9.60 ± 5.00	.99
Elbow extensors (49)	8.02 ± 3.68	8.00 ± 3.58	7.88 ± 3.49	.98
Shoulder flexors (42)	8.74 ± 4.58	8.78 ± 4.56	8.74 ± 4.60	.99
Shoulder extensors (49)	11.62 ± 5.59	11.66 ± 5.62	11.27 ± 5.77	.93
Shoulder abductors (46)	6.29 ± 3.03	6.21 ± 3.02	6.15 ± 3.06	.97
Hip flexors (51)	7.14 ± 3.48	7.01 ± 3.43	6.91 ± 3.45	.95
Hip extensors (47)	14.77 ± 5.59	15.02 ± 5.69	14.95 ± 5.56	.99
Hip abductors (52)	10.34 ± 4.23	10.36 ± 4.25	10.40 ± 4.16	.99
Knee flexors (48)	6.41 ± 3.21	6.34 ± 3.29	6.38 ± 3.33	.99
Knee extensors (51)	13.00 ± 6.43	13.16 ± 6.60	13.12 ± 6.63	.99
Ankle plantar flexors (47)	10.95 ± 5.49	11.00 ± 5.44	11.12 ± 5.51	.98
Ankle dorsiflexors (45)	6.39 ± 3.74	6.37 ± 3.69	6.41 ± 3.78	.99

Values are mean ± SD of strength measures and the results of the analysis of variance (ANOVA) regarding the comparisons between the different scoring methods for the strength of the upper and lower limb muscles, assessed with a hand-held dynamometer.

limb coordination with the Lower Extremity Motor Coordination Test with 320 healthy individuals [19]. Corroborating previously reported findings, no significant differences were found regarding the different scoring methods (.10 ≤ *P* ≤ .92) [19].

The present findings support the use of a single trial of muscle strength assessment, after familiarization (Table 2), for individuals with both sub-acute and chronic stroke. This has important clinical implication for both clinicians and researchers, as valuable time can be saved. In addition, it is also convenient for individuals with stroke, as they will have less discomfort during the assessments. Furthermore, it may also allow measurement of strength of individuals with stroke with more severe impairments, who could perform the strength measure once but could not repeat it several times. Therefore, these findings may improve the clinical applicability of hand-held dynamometers for muscle strength assessment after a stroke.

This study has limitations. First, although the sample was broad and drawn from various settings, it was not randomly selected and may not, therefore, be fully representative of the stroke population. Second, because the recruitment process was conducted on a volunteer basis, those participants, who agreed to be included in the study, may differ from the general community. Third, most of the participants had mild motor impairments, rather than moderate or severe ones. Finally, despite assessing the strength of 14 muscle groups, measures of other muscle groups, such as shoulder and hip internal/external rotators, were not obtained. Future studies should address these issues.

Conclusion

Only a single trial, after familiarization, may be used for measuring the strength of the upper and lower limb muscles with hand-held dynamometers in individuals with both sub-acute and chronic stroke. This increases the clinical applicability of the hand-held dynamometer for the measurement of strength after stroke, as it reduces the assessment burden placed on the patients and therapists.

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Disclosure

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Disclosure: nothing to disclose

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Disclosure: nothing to disclose

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Disclosure: nothing to disclose

Supported by the Coordenaç aõ de Aperfeiç oamento de Pessoal de Nível Superior (CAPES), Fundaç aõ de Amparo á Pesquisa do Estado de Minas Gerais (FAPEMIG), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Pró-Reitoria de Pesquisa, Universidade Federal de Minas Gerais (PRPq/UFMG).

Submitted for publication March 28, 2018; accepted August 4, 2018.