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RESEARCH LETTER

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Age-related influence on reliability and learning effect in the assessment of lower limb strength using sit-to-stand tests: A cross-sectional study

1 | INTRODUCTION

Decreased muscle strength, especially in the muscles of lower limbs, is an important risk factor for early age-related decline in physical function, morbidity, hospitalization, and mortality.[1] This evidence should be a stimulus for healthcare professionals to include the assessment of muscular strength as a priority in the community due to its substantial value in predicting future health status.[2]

For this purpose, sit-to-stand tests represent one of the simple and valid options to quantify lower limb strength,[3] and two of the most used are the 1-min sit-to-stand (1MSTS)[4] and the 5 times sit-to-stand (5TSTS).[5] To standardize the use of 1MSTS and 5TSTS, it is important to explore whether a similar reliability and learning effect exist between adults and older adults in community settings. Since aging may cause a significant reduction in motor skill acquisition,[6] it is important to carefully consider whether performances on these tests are the same for repeated measurement over time (test-retest) and if a practice test is needed according to age. Another reason to establish the reliability and learning effect, before recommending the use of the sit-to-stand tests for adults and older adults, is because significantly different performances have been found between these populations.[7,8]

With this research, we aimed to determine the within-day test-retest reliability and the learning effect of the 1MSTS and 5TSTS in adults (<60 years) and older adults (≥60 years).

2 | METHODS

A cross-sectional study was designed and data collection was conducted between March 2021 and April 2022 at a university campus and surrounding areas (e.g., fitness centers, community centers, senior universities). Reporting follows Strengthening The Reporting of Observational Studies in Epidemiology (STROBE) Guidelines,[9] the Ethical Committee of the School of Health—Polytechnic of Porto, Portugal approved the study (code number: CE0013B 24/02/2021), and all participants signed an informed consent form. Sample size was defined according to COnsensus-based Standards for the selection of health status Measurement INstruments (COSMIN) guidelines, which recommend that a minimum of 50 individuals should be recruited to ensure the quality of studies assessing the measurement properties (e.g., reliability) of tests.[10]

The study was advertised for people aged >18 years through emails and phone contacts. To ensure maximum inclusion of community-dwelling people, those with prevalent age-related conditions such as hypercholesterolemia, hypertension, and diabetes were also targeted. Participants meeting any of the following conditions were excluded from the study: acute (within the past 4 weeks) or chronic respiratory disease, cardiac disease, indications of cognitive or neuromuscular impairment, and significant musculoskeletal disorders (such as ankylosing spondylitis) that might impede the performance of sit-to-stand tests.

Participants completed three repetitions of 1MSTS and 5TSTS, separated by 5 min of rest between repetitions of the same test and 10 min of rest between the tests. The sequence of performing the sit-to-stand tests was not predetermined. In this study, we followed the latest recommendations provided by Furlanetto et al.[11] to conduct the sit-to-stand tests. During both tests, participants commenced from a seated position on a chair (with a standardized seat height of 46 cm), with feet placed flat on the floor and arms crossed over their chests. They were instructed to rise from the chair and return to a seated position as swiftly as possible, ensuring a firm landing. Full extension of the knees was required to achieve a standing position, while the buttocks had to make full contact with the chair to achieve a seated position (with no requirement for the participants' backs to touch the chair back). The use of arms for assistance was not allowed during the tests. For the reliability and learning effect analysis, the best performance was determined based on the highest number of repetitions for the 1MSTS and the shortest completion time for the 5TSTS.

Established recommendations for statistical analyses, reporting and interpretation of the results were applied.[12] Statistical analysis was performed using IBM SPSS Statistics (version 28) and the level of statistical significance was set at $p < 0.05$. Descriptive statistics were used to describe the total sample and the subgroups: adults (aged <60 years) and older adults (≥60 years). Participants' characteristics were compared between adults and older adults using independent *t*-tests for normally

distributed data, Mann–Whitney *U* tests for non-normally distributed data, and Chi-square test or Fisher's exact test for categorical data, when appropriate. The intraclass correlation coefficient (ICC) model 2 (two-way random effects), absolute agreement, with a single rater ($ICC_{2,1}$), the standard error of measurement (SEM) and the minimal detectable change at 95% CI (MDC95) were calculated to assess the test-retest reliability. A %MDC95 of less than 30% was considered acceptable. The learning effect was explored using the Friedman test and post hoc analyzes were conducted with Wilcoxon signed-rank tests using Bonferroni correction to compare the performance between the three attempts of the 1MSTS and 5TSTS. The percentage of variation by the learning effect was also calculated between the first-second tests and the second-third tests.

3 | RESULTS

In total, 445 participants completed the study (range: 18–91 years; 269 [60.4%] females and median body mass index 24.49 [22.14–27.24] kg/m^2). Characteristics of all participants, adults and older adults are shown in online Table S1.

High $ICC_{2,1}$, small SEM and acceptable MDC95 values were found in the total sample, in adults and older adults (Table 1). Significant differences ($p < 0.001$) were only found between the attempts of 1MSTS and 5TST in adults (Table 2).

4 | DISCUSSION

This research showed excellent within-day test-retest reliability for the 1MSTS and 5TSTS in adults and older adults. Our ICC values (0.90–0.98) were similar to those reported from other studies which also recruited participants from general community, such as Muñoz-Bermejo et al.[13] (0.93 for 5TSTS) and Furlanetto et al.[11] (0.95 for 1MSTS and 0.86 5TSTS). Additionally, similar SEM and MCD95 values were also found suggesting a low variation in the measurement error of sit-to-stand tests. In fact, % MDC95 values of our study were lower than 30%, suggesting that the amount of change that can be detected in sit-to-stand performance that corresponds to a noticeable change is acceptable. Another interesting fact is that even in clinical populations

TABLE 1 ICC, SEM, and MDC_{95} values of the 1MSTS and 5TSTS for total sample, adults (<60 years) and older adults (≥60 years).

	Total sample (*n* = 445)	Adults (*n* = 363)	Older adults (*n* = 82)
1MSTS (number of repetitions)			
$ICC_{(2,1)}$ (95% CI)	0.92 (0.89–0.94)	0.90 (0.86–0.93)	0.93 (0.90–0.95)
SEM (%)	3.40 (9.74)	3.65 (9.81)	2.03 (8.31)
MDC95 (%)	9.41 (27.0)	10.12 (27.20)	5.63 (23.03)
5TSTS (seconds)			
$ICC_{(2,1)}$ (95% CI)	0.98 (0.97–0.99)	0.98 (0.97–0.98)	0.98 (0.97–0.99)
SEM (%)	0.52 (6.41)	0.41 (5.57)	0.66 (5.76)
MDC95 (%)	1.43 (17.76)	1.13 (15.4)	1.83 (15.98)

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; MDC95, minimal detectable change at 95% confidence interval; 1MSTS, 1-min sit-to-stand; SEM, standard error of measurement; 5TSTS, 5 times sit-to-stand.

TABLE 2 Median values and learning effect of the three attempts in the 1MSTS and 5TSTS for adults (aged <60 years) and older adults (≥60 years).

	Tests			Learning effect (%)	
	Test 1	Test 2	Test 3	Test 1–Test 2	Test 2–Test 3
1MSTS (number of repetitions)					
Adults	34 (27–44)	36 (29–45)[a]	38 (29–48)[a,b]	5.0 ± 10.8	4.1 ± 10.1
Older adults	24 (19–28)	24 (20–28)	24.5 (19–28)	2.5 ± 11.5	0.4 ± 11.1
5TSTS (time)					
Adults	6.85 (5.37–8.98)	6.64 (5.09–8.67)[a]	6.52 (5.02–8.39)[a,b]	−2.6 ± 7.1	−2.1 ± 6.2
Older adults	11.05 (7.98–12.50)	11.12 (8.53–12.33)	10.69 (8.51–12.48)	−0.2 ± 8.2	−1.2 ± 6.6

Note: Data presented as median (percentile 25–75) or mean ± standard deviation.

Abbreviations: 1MSTS, 1-min sit-to-stand; 5TSTS, 5 times sit-to-stand.

[a]Different from Test 1.

[b]Different from Test 2; all *p* values <0.001 adjusted by the Bonferroni correction.

(e.g., pulmonary, neurological and musculoskeletal diseases) excellent and similar reliability results were found,[4,14] proving that the performances on 1MSTS and 5TSTS tests are consistent over time in different populations.

According to the learning effect results, a systematic increase in 1MSTS and decrease in 5TSTS—indicating a learning effect—was found in adults, but not in older adults. The absence of a learning effect in older adults can be explained, as previously mentioned, by the negative influence of aging on functional capacity. Aging is accompanied with changes in sensory and motor system, which may cause significant reduction in motor skill acquisition in older adults.[6]

As a strength, the current study has a high degree of generalizability as it recruited from the general population. However, the study focused only on the age influence, omitting the possible influence of other variables, such as sex, physical activity, or profession. Thus, further studies should focus on the influence that these variables might have on the reliability and learning effect of sit-to-stand tests.

In conclusion, 1MSTS and 5TSTS showed excellent within-day test-retest reliability in adults and older adults. Our findings also suggest that at least three 1MSTS and 5TSTS tests are needed for adults to achieve their individual real performance. On the other hand, a single 1MSTS and 5TSTS may be sufficient in older adults. These results may be useful to standardize the number of tests to be performed in the assessment with the 1MSTS and 5TSTS.

KEYWORDS

aging, lower limb strength, outcome assessment, sit-to-stand tests

AUTHOR CONTRIBUTIONS

All authors: read and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data generated or analyzed during this study are included in this article and can be requested from the corresponding author. Rui Vilarinho full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

TRANSPARENCY STATEMENT

The lead author Rui Vilarinho affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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