

Assessing muscle fitness changes to resistance training in healthy young adults using the 1-min sit-to-stand test: insights from a mobile app analysis

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Abstract

Purpose Beyond its clinical relevance, the 1-min sit-to-stand test (1STS) has gained attention in the general population as a measure of physical fitness. Relying solely on repetition counts may limit the interpretability of the 1STS following a training program aimed at improving muscle condition. We aimed to assess 1STS changes after a resistance program, incorporating strength and fatigability performance metrics for a more comprehensive evaluation.

Methods 23 healthy, active participants were randomly assigned to a training or control group. The training group followed a 4-week resistance program with short rest intervals (the 3/7 method) to improve muscle strength and local muscle endurance. Performance fatigability, sit-to-stand time, velocity, and power were assessed using a mobile app from a single sit-to-stand maneuver together with the number of repetitions performed (1STS_{REP}). Maximum theoretical load (L_0), velocity at zero load (v_0), the area under the load–velocity curve (A_{line}), and one-repetition maximum (1RM) were estimated using a linear encoder from a load–velocity test.

Results The training group improved 1STS_{REP} (+16%), Sit to Stand app parameters (+8–25%), 1RM (+36%), and load–velocity metrics (L_0 : +45%, A_{line} : +27%) (all $P < 0.05$), with no change in v_0 . No changes were observed in the control group. Improvements in 1STS_{REP} correlated with A_{line} ($r = 0.379$, $P = 0.031$) and Sit to Stand app parameters ($r = 0.45–0.49$, $P < 0.05$). The training had no effect on performance fatigability.

Conclusion These findings suggest that 1STS performance improvements result from strength-related gains rather than muscle endurance, informing better training strategies for lower-body functional capacity.

Keywords Functional performance · Fatigability · Strength training

Introduction

Physical inactivity is prevalent worldwide, contributing to poor physical fitness, cognitive decline, and an increased risk of non-communicable diseases (Booth et al. 2017; Strain et al. 2024). Individuals with risk factors who exhibit

reduced exercise capacity face a higher relative risk of death compared to those with normal exercise capacity (Myers et al. 2002).

Regular physical activity is well established as an effective means of enhancing fitness and preventing chronic diseases (Warburton et al. 2006). In particular, resistance training, recommended by the World Health Organization at least twice weekly for major muscle groups at moderate or greater intensity (Bull et al. 2020), has been consistently linked to reduced all-cause mortality, lower risk of major non-communicable diseases, and improved physical function (El-Kotob et al. 2020; Momma et al. 2022). It plays a critical role in primary prevention by enhancing muscle strength (Currier et al. 2023) and local muscle endurance through specific physiological mechanisms (for strength: fiber hypertrophy, neural adaptations, increased motor unit recruitment; for endurance: increased mitochondrial density, enhanced

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capillarization), and overall fitness across the life span, from childhood (Lesinski et al. 2020) to adulthood (Weiss et al. 2010) and into aging (Smart et al. 2022). Beyond long-term health benefits, resistance training supports daily activities that are directly dependent on muscle strength capacity (Warburton et al. 2006).

Assessing muscle fitness (e.g., strength, local muscle endurance, power, fatigability) is essential for tailoring resistance training programs and evaluating their effectiveness. However, physical activity providers face challenges in conducting these assessments in a practical, efficient, and reliable way (Till et al. 2023; Klein et al. 2025; Pilutti et al. 2015). Traditional strength metrics, such as maximal isometric strength measured with isokinetic dynamometers, are costly and may not reflect functional muscle performance (Grgic et al. 2020). Other assessments, such as the one-repetition maximum (1RM), more closely represents real-life tasks (Grgic et al. 2020), but requires time, expertise, and may not be suitable for frail individuals (Rosenberger et al. 2021; Di Fabio 2001) or those without resistance training experience (Arazi and Asadi 2013). While these tests focus on maximal strength, local muscle endurance is equally important for daily activities. Assessing both muscle strength and endurance is often too time-consuming for routine clinical or preventative settings (Gruther et al. 2009).

In this context, the 1-min sit-to-stand (1STS) has emerged as a simple, time-efficient, and functional assessment that captures both lower limb strength and endurance in primary prevention (Strassmann et al. 2013; Reychler et al. 2020) and clinical settings (Saynor et al. 2023) through the number of repetitions (1STS_{REP}) performed over 1 min. It is sensitive to training-induced improvements (Bohannon and Crouch 2019) and declines from disease-related muscle weakness (Hardy et al. 2022) or acute respiratory exacerbations (McDonald et al. 2023). Nevertheless, two points are noteworthy. First, its time cap can create a ceiling effect, masking actual improvements in individuals with higher physical capacity or mild conditions (Saynor et al. 2023). Second, by design, the 1STS reflects a combination of muscle strength and local muscle endurance, which is appropriate for a functional exercise capacity test where these components naturally interact (Saynor et al. 2023; Souron et al. 2024b). However, for certain purposes (e.g., evaluating the specific physiological adaptations to resistance training), it can be valuable to distinguish the relative contributions of strength and local muscle endurance. To address this, we developed and validated a mobile app that analyzes the sit-to-stand movement using high-speed video (Ruiz-Cardenas et al. 2018). The app provides valid and reliable kinetic and kinematic parameters (Ruiz-Cardenas et al. 2018; Souron et al. 2024b) from a single sit-to-stand maneuver, enabling precise evaluation of both acute and chronic adaptations to resistance training. It primarily captures on muscle strength

through metrics like rising time, vertical velocity, and power. The app also quantifies fatigability (Souron et al. 2024a, 2024b), defined as a decline in objective measures of muscle performance (Enoka and Duchateau 2016). In the context of this study, fatigability refers specifically to the pre-post 1STS reduction in app-derived parameters (e.g., rising time, velocity, or power). Using this app, we recently assessed sit-to-stand performance before and after the 1STS test (Souron et al. 2024b), finding that over 74% of young healthy adults showed a decline in performance indicators. Less fatigable individuals performed better on the 1STS, supporting the app's construct validity in measuring local muscle endurance. Differentiating whether improvements in 1STS_{REP} after training stem from enhanced local muscle endurance (i.e., reduced fatigability) or muscle strength (i.e., increased muscle power, velocity, and consequently rising time) may provide important physiological and practical insights. Ultimately, a better understanding of 1STS_{REP} changes and the underlying factors with resistance training may promote its use in several settings, as a simple tool to monitor training-induced adaptations in muscle fitness.

This study investigated whether improvements in 1STS performance after a 4-week resistance training program were driven by increases in muscle strength, local muscle endurance, or both, using a specifically designed mobile app. Since 1STS gains can result from enhanced strength and/or velocity, we also analyzed load-velocity profiles to better understand the maximal capacities of the neuromuscular system and its influence on 1STS performance (Pérez-Castilla et al. 2021). We hypothesized that changes in the load-velocity relationship and sit-to-stand performance indicators from the app would explain the improved 1STS performance after training.

Methods

Participants

Recreationally active participants who did not regularly engage in resistance training and had no contraindication for physical exercise were eligible. Participants with any physical condition impairing their ability to perform the proposed tests were excluded. A minimum of 20 participants (10 per group) were required to detect a large effect (Cohen's $d=0.80$) with 90% statistical power at $\alpha=0.05$ for the time $\times$ group interaction in a mixed-design ANOVA, assuming a nonsphericity correction $\epsilon=1.0$ and a correlation of 0.5 between repeated measures (G*Power 3.1). This effect size was chosen based on previous studies employing a similar resistance training design (Stragier et al. 2019; Duchateau et al. 2020). Accounting for a 15% dropout rate,

24 participants were initially enrolled to ensure sufficient statistical power.

Randomization was performed using a predetermined Excel sheet with a 1:1 ratio distribution. Due to the design of the intervention, neither participants nor the trainer were blinded. However, to minimize bias, data from the app, 1STS, and linear encoder were analyzed by a researcher blinded to group allocation, and all statistical analyses were performed using coded group assignments. This study adhered to the Declaration of Helsinki and was approved by the Ethical Committee of Nantes University (n° IRB: IORG0011023). Participants were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

Procedures

General design of the study. This was a single center, parallel-group randomized controlled trial conducted at the Motricity Interaction and Performance (MIP) Laboratory of the Sport Sciences Faculty at Nantes University, from January 2024 to April 2024.

Participants attended the laboratory on two separate visits: once before and once 3–4 days after the intervention period. During the first visit, participants received a detailed explanation of the study procedures, and written informed consent was obtained. Participants underwent a familiarization process and warm-up protocol to ensure they were fully prepared for testing. The warm-up included a 5-min incremental cycling exercise on a stationary bike (Stages Bike SB20 Smart Bike, Stages Cycling), with intensity auto-regulated using the Borg 6–20 Rate of Perceived Exertion (RPE) scale (Borg and Kaijser 2006). Participants gradually increased their effort intensity, starting at an RPE of 7 and increasing by 2 every 90 s, until reaching an RPE of 13. Then, they performed ten chair rises, with direct feedback from the examiner to ensure proper execution, including no use of hands, contact between the buttocks and the chair, and correct foot placement. After the warm-up, testing procedures commenced and were repeated after 30 min of rest for test–retest reliability analysis.

A single sit-to-stand movement was performed to calculate rising time, vertical velocity, and power during the rising phase, using our validated *Sit to Stand* mobile app (Ruiz-Cardenas et al. 2018). The single sit-to-stand movement was performed before and immediately after the 1STS to assess performance fatigability, following a previously published protocol (Souron et al. 2024b). After completion of the 1STS and a standardized ≈ 10 -min recovery period, the load–velocity relationship during a box squat exercise was estimated using the two-load method (Garcia-Ramos and Jaric 2018). Finally, the 1RM for the box squat exercise

was estimated based on the individual load–velocity relationship. More information about the test sequence is presented in Fig. 1.

After the initial session, participants were informed of their group assignment. Participants in the training group followed a resistance training protocol three times per week for 4 weeks, with the final measurement session conducted 3 days after the intervention to minimize the effects of residual fatigue. Participants in the control group maintained their usual activity levels and attended only the final measurement session.

Training description. The training group followed an intervention based on the 3/7 resistance training method (Duchateau et al. 2020; Stragier et al. 2019). This protocol was specifically chosen because it elicits neuromuscular adaptations (Stragier et al. 2019) that contribute to increases in strength, power, and functional sit-to-stand performance, directly aligning with the main outcomes assessed in this trial (i.e., 1STS_{REP}, app-derived parameters from a single sit-to-stand movement).

Participants performed five sets of barbell box squats (Olympic weightlifting bar, 20 kg) on a 46-cm box (Fig. 1) at 70% of their estimated 1RM during the initial training session. They were instructed to perform each repetition through the same range of motion, lowering the load in a controlled manner over 2–3 s (eccentric phase) and lifting it with maximal velocity intent (concentric phase). Participants were instructed to sit fully on the box with a 1-s pause at the bottom of each repetition to avoid inertia. The first set consisted of three repetitions, with one repetition added to each subsequent set. Rest between sets was 15 s. If a participant could not complete the prescribed numbers of repetitions, the supervisor provided the minimal assistance necessary to finish the set. The initial load (i.e., 70% 1RM) corresponded to the maximal load allowing ≈ 12 –15 repetitions (Nuzzo et al. 2024b). Training load was increased by 2.5–5% once the participant successfully completed the protocol in two consecutive sessions. Training was performed three times per week for 4 weeks (12 training sessions), with at least 24 h between sessions. All sessions were supervised. Prior to each session, participants completed a standardized warm-up consisting of 8 min of cycling (Stages Bike SB20 Smart Bike, Stages Cycling) at the previously specified levels of effort perception, followed by two sets of 10 bodyweight squats. During the first laboratory visit, participants were extensively familiarized with the box squat procedures (i.e., technical execution, cadence control, and safety) to reduce potential difficulties among those without regular resistance training experience, particularly in accurately estimating their 1RM and performing the movement safely.

1-min sit-to-stand. The 1STS was performed using a standardized chair, 46 cm in height, without armrests, following recommended procedures (Bohannon and Crouch

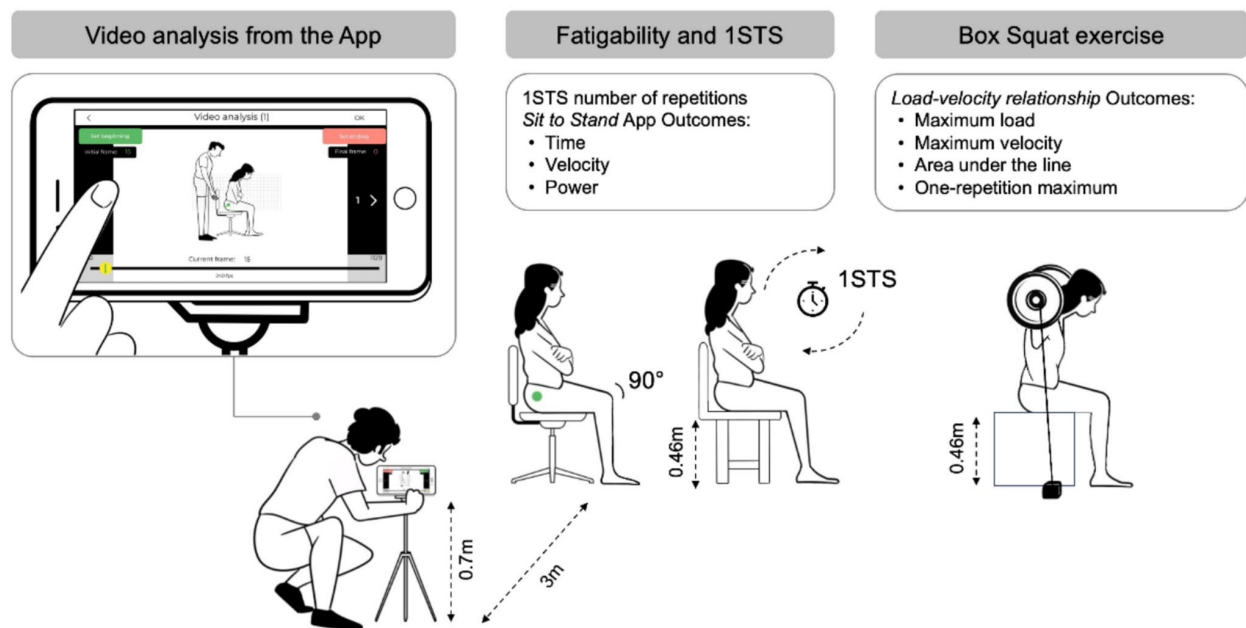


Fig. 1 Assessment procedures. Participants performed a single sit-to-stand test before and immediately after the 1-min sit-to-stand test (1STS). The movement was recorded at 240 frames per second using the Sit to Stand app on a smartphone. During video analysis, a visual marker (green dot) was placed on the greater trochanter to define the start and end of the rising phase, following the app's instructions. The

app then provided measurements for rising time, vertical velocity, and power. Performance fatigability was assessed by comparing these values before and immediately after the 1STS. Additionally, the individual load-velocity profile was determined using a linear position transducer, providing estimates of maximum load (L_0), maximum velocity (v_0), area under the curve (A_{line}), and one-repetition maximum (1RM)

2019). The chair was positioned against a wall to ensure participant safety. Standardized instructions were provided, instructing participants to stand fully upright with complete knee extension, then immediately sit back down with the buttocks touching the chair, performing as many repetitions as possible within 1 min. No verbal encouragement was given. After 45 s of effort, participants were informed of the remaining time in a neutral tone (Haile et al. 2021). The entire exercise was recorded on video and later analyzed to exclude invalid repetitions, such as those lacking full extension or failing to touch the chair with the buttocks. The number of valid repetitions performed during the 1STS (i.e., $1STS_{REP}$) was used for further analysis. The test-retest analysis performed in the current trial for $1STS_{REP}$ showed excellent reliability with an intra-class correlation coefficient (ICC_{2-1}) of 0.94 and a minimal detectable change (MDC_{95}) of 3 reps.

Single STS-derived outcomes and performance fatigability. A single sit-to-stand maneuver was performed to determine the mean rising time, vertical velocity, and power generated during the rising phase of the movement. The test was recorded at 240 frames per second using the *Sit to Stand* app (v. 2.0.2) installed on an iPhone 13 Mini (Apple Inc., Cupertino, CA, USA) running iOS 15.3. The instructions from a previously validated version of the test were followed

(Ruiz-Cardenas et al. 2018), with the recording device positioned on a 0.7-m high tripod placed 3 m perpendicularly to the participant. For these isolated sit-to-stand maneuvers, we used an adjustable chair with a flat seat and no armrests, allowing for precise adjustment of the knee angle to exactly 90° for each participant. This chair was placed next to the standard chair used for the 1STS test to facilitate a smooth transition for post-measurements immediately following the completion of the 1STS test. Participants started from a sitting position with their legs hip-width apart, and the ankle, knee, and hip joints at 90°. They were instructed to stand up as quickly as possible, once, while keeping their arms crossed over their chest. A trial was considered valid if the participant achieved full knee extension while keeping their heels on the ground, with no visible heel raise. According to mobile app's instructions, a colored visual sticker was placed on the greater trochanter to help identify key frames. The first frame was identified when the pelvis initiated forward movement following anterior trunk tilt and was synchronized with the moment the colored visual sticker crossed the initial horizontal grid line on the app's screen. The second frame marked the conclusion of the movement cycle, characterized by full extension of the hip and knee in an upright stance (see Fig. 1, or Fig. 2 in Ruiz-Cardenas et al. (Ruiz-Cardenas et al. 2018) for a zoomed display). This position coincided

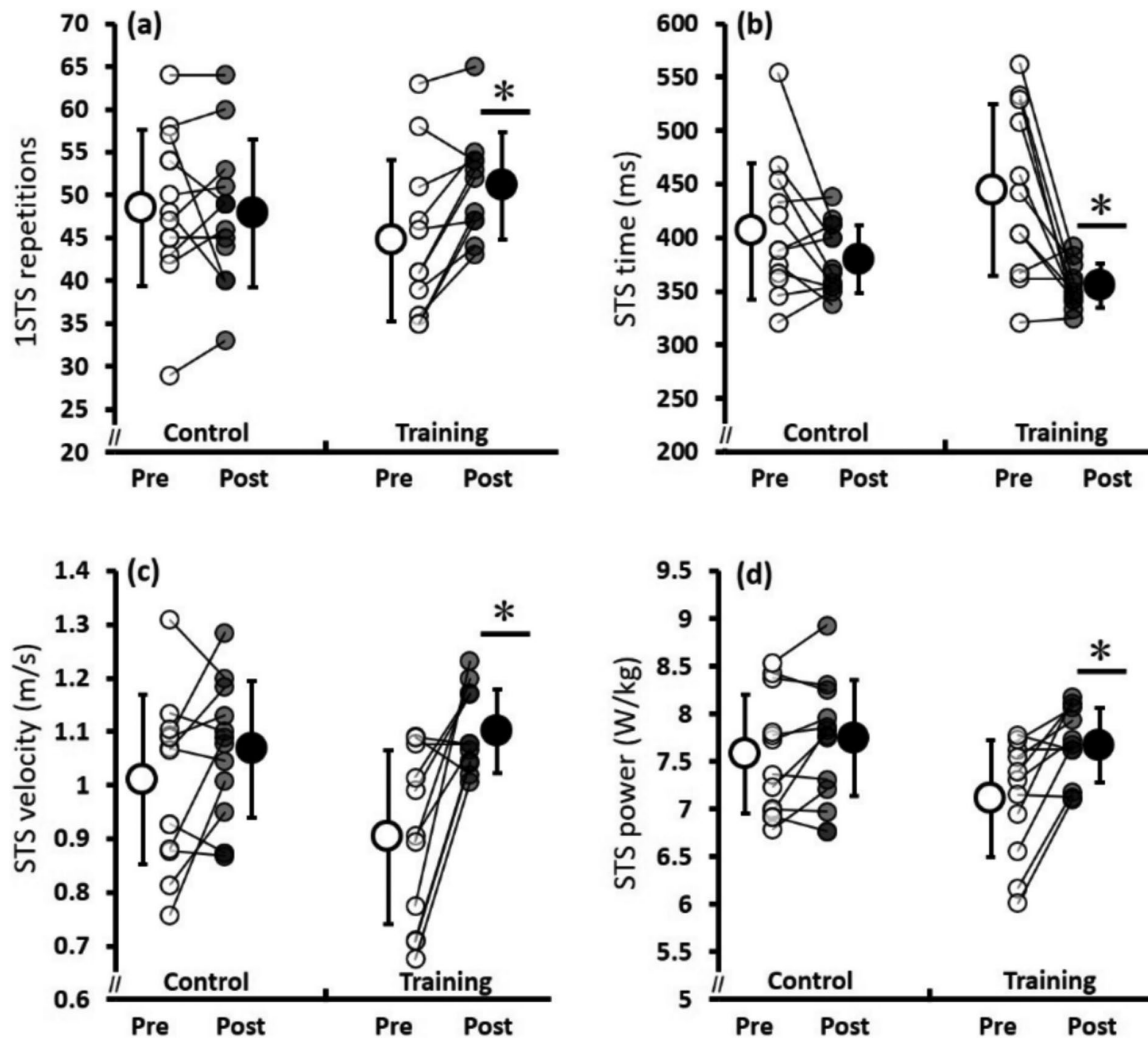


Fig. 2 Pre- vs. post-intervention results (control vs. training) for the number of repetitions completed during the 1-min sit-to-stand test (1STS, panel A), and the parameters extracted from the Sit to Stand app: rising time (panel B), vertical velocity (panel C) and power

(panel D). Large circles represent mean values $\pm$ standard deviation, while small circles correspond to individual data points connected by solid lines. * denotes a significant difference between post- and pre-intervention data, with $P < 0.05$

with the point when the colored visual sticker reached its highest vertical position during the upright movement cycle. The app automatically provides results for rising time (i.e., the time from seat-off to full lower limb extension), velocity (i.e., femur length divided by rising time), and mean power, based on the previously validated equation:

$$\text{Mean power (W/kg)} = 2.773 - 6.228 \times t + 18.224 \times d,$$

with t representing the rising time, and d corresponding to the distance covered (i.e., femur length). This test was performed immediately before and after the 1STS to assess performance fatigability, defined in our context as the pre-post 1STS differences in rising time, velocity, and power. Excellent test-retest reliability has been demonstrated for these fatigability indicators in a sample with comparable

characteristics (Souron et al. 2024b), with ICC_{2,1} of 0.95 for rising time (MDC₉₅: 0.032 s), 0.97 for velocity (MDC₉₅: 0.052 m/s), and 0.99 for power (MDC₉₅: 0.198 W/kg).

Load-velocity relationship and one-repetition maximum (1RM). The individual load-velocity relationship was determined during the box squat exercise using a previously validated two-load method (Garcia-Ramos and Jaric 2018). This method was chosen because it demonstrates excellent construct validity with the force-velocity relationship while offering greater reliability, especially for estimating the theoretical maximum velocity, i.e., v_0 (Pérez-Castilla et al. 2021). Participants underwent a familiarization process to ensure proper execution of the movement. They were instructed to stand up as quickly as possible from a

standardized 46 cm-high box with an Olympic bar loaded on their shoulders, achieving full lower limb and hip extension. Once participants were familiar with the movement, a brief warm-up consisting of two sets of ten repetitions with progressively increasing load (50–70% of self-reported 1RM) was performed. Next, one load around 40–50% and one load between 70 and 90% of self-reported 1RM were selected to determine each individuals' load–velocity profile. The velocity of each lift was tracked using a linear position transducer (Chronojump, Boscosystem, Barcelona, Spain), and the mean propulsive velocity was recorded. Two trials were allowed for each load. If the coefficient of variation exceeded 10%, a third trial was performed. The best mean propulsive velocity achieved for each load was used in the load–velocity modeling. Our internal analysis demonstrated excellent test–retest reliability for movement velocity, with ICC₂₋₁ values of 0.93 for loads ranging from 40 to 50% 1RM and 0.88 for loads ranging from 70 to 90% 1RM. The load–velocity profile was obtained from the following least-squares linear regression model, consistent with previous studies (Pérez-Castilla et al. 2021):

$$(L[V] = L_0 - sV),$$

with L_0 representing the maximal load when velocity is zero, and s denoting the slope of the load–velocity relationship. Hence, v_0 was calculated by dividing L_0 for the slope of the curve ($v_0 = L_0/s$). The area under the load–velocity line (A_{line}) was calculated as the product of L_0 and v_0 , divided by 2 ($A_{line} = L_0 \times v_0/2$). Once the load–velocity profile was obtained, theoretical 1RM was estimated by setting the minimum velocity threshold of the 1RM at 0.33 m/s (Conceição et al. 2016).

Statistical analysis

Statistical analyses were performed using JASP software (version 0.18.3, JASP Team). The Shapiro–Wilk test was applied to confirm the normality of the data. A repeated measures ANOVA was first conducted to assess whether the 1STS test induced fatigability, defined as a reduction in sit-to-stand time, velocity, and power from the single sit-to-stand maneuver. Subsequently, a mixed-design ANOVA (time $\times$ group) was performed to evaluate the effects of the training intervention and to examine time-by-group interactions for each dependent variable. Since improvements in 1STS_{REP} after the training period could influence indicators of performance fatigability, it was included as a covariate. Levene's test was used to check the homogeneity of variances across groups for each variable at each time point. Effect sizes were reported as partial eta squared (η^2), with $\eta^2 \geq 0.07$ and $\eta^2 \geq 0.14$ interpreted as moderate and large effects, respectively. Significant effects were further examined using post hoc pairwise comparisons with the Bonferroni correction, and Cohen's d effect size were calculated.

The MDC₉₅ was calculated as $SEM \times \sqrt{2} \times 1.96$. The MDC₉₅ can be interpreted as the minimal amount of change in the score of an instrument that must occur in an individual to be sure that the change in score is not simply attributable to a measurement error. Participants whose improvements exceeded the MDC₉₅ after the training period were classified as responders, while those whose performance declines exceeded the MDC₉₅ after the 1STS were classified as fatigable. To assess whether changes in 1STS performance were associated with changes in sit-to-stand time, velocity, power, 1RM, or variables derived from the load–velocity relationship, Pearson correlation coefficients were calculated. Statistical significance was set at $P < 0.05$.

Results

Participants

A total of 24 healthy young adults were assessed for eligibility. One participant withdrew before the experimental protocol due to incompatibility, resulting in 23 healthy young adults (14 females; mean age: 21 ± 3 ; IPAQ-SF: 4049 ± 2200 METs-min-week-1) being recruited and randomly assigned to either the training ($n = 11$) or control group ($n = 12$). Training adherence was 100%, with all participants in the training group completing the 4-week resistance training protocol and attending all 12 scheduled sessions. Detailed anthropometric and physical activity data for each group are presented in Table 1, and participant flow is illustrated in supplementary material (see Supplementary Material, Figure S1).

Effects of training on the number of repetitions completed during the 1STS. Significant main effects of time and time-by-group interactions were observed ($P < 0.05$). The training group demonstrated a $16.4 \pm 14.4\%$ improvement in 1STS_{REP}, with a mean increase of 6.3 ± 5.5 repetitions ($P = 0.014$), while no significant changes were detected in the control group (mean change: 0.6 ± 6.6 repetitions) (Fig. 2a). Responder analysis revealed that 64% (7/11) of

Table 1 Participant characteristics

	Training group ($n = 11$)	Control group ($n = 12$)
Female, n (%)	6 (54)	8 (66)
Age (years)	20.7 (1.8)	21.9 (3.8)
Height (m)	1.7 (0.1)	1.7 (0.1)
Body mass (kg)	61.5 (7.4)	59.7 (8.2)
Physical activity (METs-min-week-1)	4389.7 (2437.4)	3737.4 (2014.2)

Data are presented as mean and standard deviation for normally distributed variables, and n (%) for categorical variables

participants showed pre-post training improvements in 1STS_{REP} that exceeded the minimal detectable change of 3 reps. Improvements in 1STS_{REP} were significantly correlated with pre-intervention 1STS_{REP} ($r = -0.771$; $P = 0.005$), with participants with higher baseline 1STS_{REP} experiencing smaller gains.

Effects of training on sit-to-stand time, velocity, power, and performance fatigability indicators. Significant main effects of time and time-by-group interactions ($P < 0.05$) were observed for sit-to-stand time, velocity, and power. The training group showed a $17.7 \pm 15.3\%$ improvement (i.e., decrease) in sit-to-stand time (mean difference of -89.2 ± 80.6 ms, $P < 0.001$, Fig. 2b), a $25.3 \pm 22.8\%$ increase in velocity (mean difference of $+0.197 \pm 0.170$ m/s, $P < 0.001$, Fig. 2c), and an $8.3 \pm 7.8\%$ increase in power (mean difference of $+0.556 \pm 0.502$ W/kg, $P < 0.001$, Fig. 2d). Responder analysis revealed that 73% (8/11) of

participants exceeded the minimal detectable change for these variables. Improvements in sit-to-stand time ($r = 0.492$, $P = 0.009$), velocity ($r = 0.451$, $P = 0.015$), and power ($r = 0.491$, $P = 0.009$) were significantly correlated with increases in 1STS_{REP}. No significant effects were observed in the control group.

Before the training period, significant fatigability was evident in performance indicators following the 1STS test. Performance declined by $17.5 \pm 16.9\%$ in sit-to-stand time ($P < 0.001$; Cohen's $d = 0.86$), $13.4 \pm 10.8\%$ in velocity ($P < 0.001$; Cohen's $d = 0.83$), and $5.5 \pm 5.1\%$ in power ($P < 0.001$; Cohen's $d = 0.86$), with no between-group differences ($P > 0.05$). More than 73% (17/23) of participants were classified as fatigable (Fig. 3). However, no significant improvements in performance fatigability were observed after the training period ($P > 0.05$; Table 2). Performance fatigability indicators remained correlated with

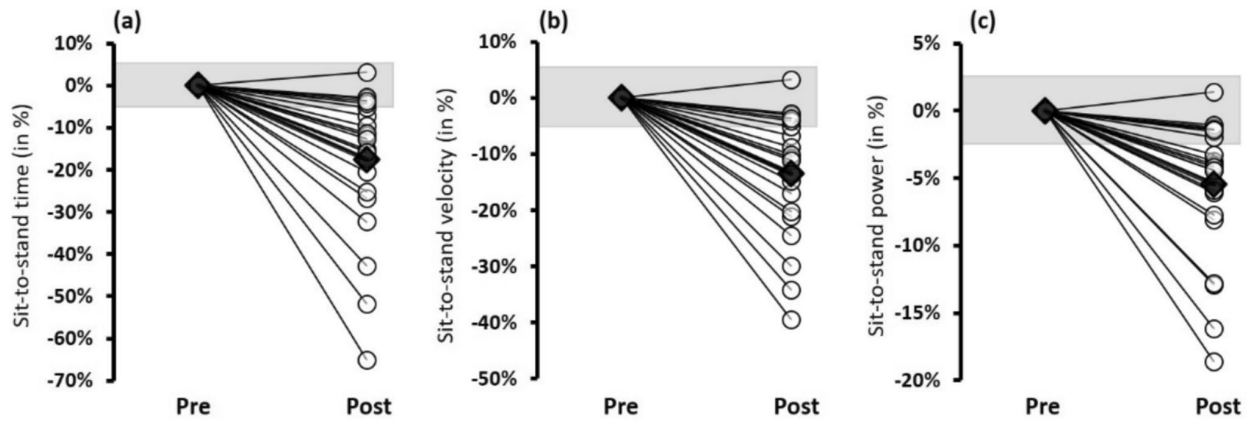


Fig. 3 Performance fatigability indicators extracted from the Sit to Stand app, with rising time (Panel A), vertical velocity (Panel B), and power (Panel C), following the 1-min sit-to-stand test performed during the initial session, before the intervention. Data are expressed

as the percentage change from baseline scores. Black diamonds connected by solid lines represent mean values, while white circles denote individual data points. The shaded gray area indicates the minimal detectable change for each performance fatigability indicator

Table 2 Pre- vs. post-intervention results (control vs. training) for 1STS, performance fatigability assessed using parameters extracted from the Sit to Stand app (time, velocity, and power), 1RM, and force-velocity relationship

	Training group		Control group		Time		Interaction	
	Pre	Post	Pre	Post	P	ηp^2	P	ηp^2
1STS _{REP}	44.7 (9.4)	51.1 (6.2)	48.5 (9.1)	47.8 (8.6)	0.04	0.19	0.01	0.27
Δ Fatigability time (ms) ^a	82.4 (82.3)	53.8 (26.4)	57.0 (43.8)	68.0 (42.4)	0.56	0.02	0.20	0.08
Δ Fatigability velocity (m/s) ^a	-0.151 (0.15)	-0.139 (0.06)	-0.122 (0.1)	-0.152 (0.1)	0.76	0.01	0.51	0.02
Δ Fatigability power (W/kg) ^a	-0.51 (0.5)	-0.33 (0.1)	-0.35 (0.3)	-0.42 (0.3)	0.56	0.02	0.20	0.08
One-repetition maximum (kg)	93.0 (38.3)	121.2 (39.2)	106.4 (33.8)	103.7 (29.2)	0.02	0.25	<0.01	0.33
Maximum velocity (V_0) (m/s)	1.19 (0.3)	1.06 (0.2)	1.03 (0.3)	1.11 (0.5)	0.74	<0.01	0.15	0.09
Maximum load (L_0) (kg)	126.3 (49.8)	174.4 (55.6)	164.6 (67.6)	155.6 (55.7)	0.04	0.17	<0.01	0.31
Area under the line (A_{line}) (kg·m/s)	74.3 (32.2)	90.8 (33.8)	77.2 (20.5)	76.8 (16.3)	0.01	0.25	0.01	0.27

Data are presented as mean and standard deviation. Δ : change in fatigability indicators (post- minus pre-1STS). ^aData are controlled for improvements in 1STS after the training period

1STS_{REP} both before and after the intervention period (r-range = 0.325–0.688, $P < 0.05$).

Training effect on theoretical maximum velocity (v_0), maximum load (L_0), area under the line (A_{line}), and one-repetition maximum (1RM). No significant effects were observed for v_0 ($P > 0.05$, Fig. 4a). However, significant main effects of time ($P < 0.05$) and time-by-group interactions were observed for L_0 ($P = 0.006$), A_{line} ($P = 0.011$) and 1RM ($P = 0.004$). The training group showed a $45.5 \pm 35.8\%$ increase in L_0 ($P = 0.012$; Cohen's $d = 0.83$, Fig. 4b), a $27.1 \pm 24.9\%$ increase in A_{line} ($P = 0.007$; Cohen's $d = 0.62$, Fig. 4c), and a $36.4 \pm 26.8\%$ increase in 1RM ($P = 0.004$; Cohen's $d = 0.8$, Fig. 4d), while no changes were observed in the control group. To account for the unusual

post-intervention decrease in 1RM observed in one control participant, a sensitivity analysis was performed excluding this case. The results remained unchanged, with comparable effect sizes for the time $\times$ group interaction ($\eta^2 = 0.326$ vs. 0.319), thereby supporting the robustness of the training effect on 1RM.

In the training group, improvements in L_0 , A_{line} , and 1RM exhibited distinct correlation patterns with 1STS_{REP} and sit-to-stand performance measures. Notably, gains in A_{line} were significantly associated with an increase in 1STS_{REP} ($r = 0.379$, $P = 0.031$), whereas L_0 ($r = 0.326$, $P = 0.064$) and 1RM ($r = 0.308$, $P = 0.077$) did not show significant relationships with this outcome. Enhancements in A_{line} , L_0 , and 1RM were significantly correlated with increases in sit-to-stand

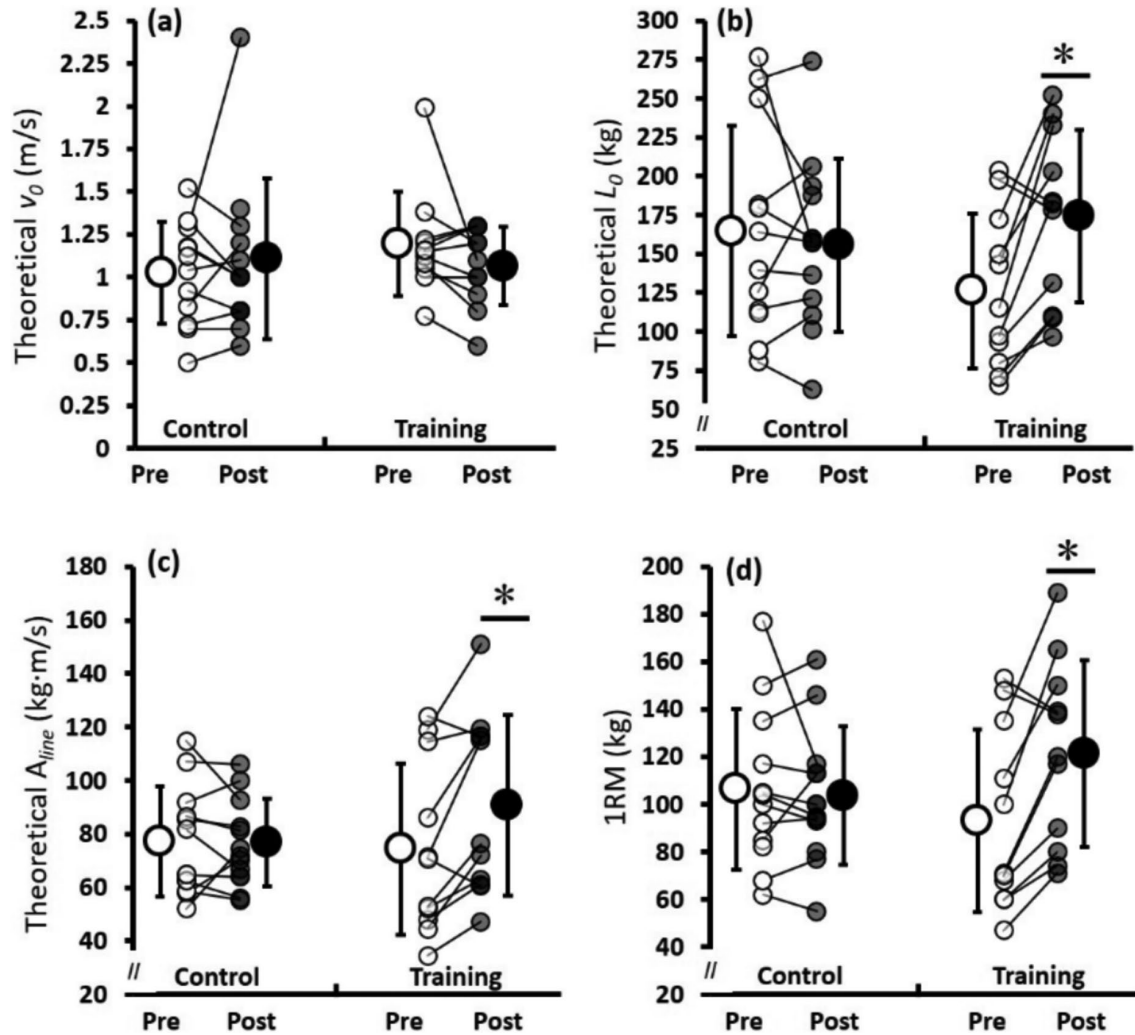


Fig. 4 Pre- vs. post-intervention results (control vs. training) for the theoretical maximum velocity (v_0 , panel A), maximum load (L_0 , panel B), area under the line (A_{line} , panel C), and one-repetition maximum (1RM, panel D). Large circles represent mean values $\pm$ stand-

ard deviation, while small circles correspond to individual data points connected by solid lines, * denotes a significant difference between post- and pre-intervention data, with $P < 0.05$

power (A_{line} : $r=0.528$, $P=0.047$; L_0 : $r=0.563$, $P=0.036$; $1RM$ $r=0.491$, $P=0.043$). Only L_0 showed a significant association with improvements in sit-to-stand velocity ($r=0.528$, $P=0.047$), while A_{line} ($r=0.517$, $P=0.052$) and $1RM$ ($r=0.482$, $P=0.067$) displayed non-significant correlations. Although trends toward significance were observed, no statistically significant relationships were found between L_0 ($r=0.502$, $P=0.058$), A_{line} ($r=0.481$, $P=0.067$), or $1RM$ ($r=0.444$, $P=0.086$) and sit-to-stand time.

Discussion

We conducted a randomized controlled trial over 4 weeks to examine the effects of resistance training on overall 1STS performance, and isolated metrics from a mobile app that informed about muscle strength and endurance, with the latter reflected by performance fatigability. The training was effective to improve maximal strength, as evidenced by a 36% increase in $1RM$. As hypothesized, the training group showed a significant improvement in the total number of sit-to-stand repetitions completed within 1 min, with a mean increase of six repetitions compared to the control group. Data from the *Sit to Stand* mobile app revealed that participants in the training group increased their rising time, vertical velocity and power during an isolated and standardized sit-to-stand movement, and that these changes were correlated with the increase in 1STS repetitions, i.e., the greater the gains in rising time, velocity and power post-training, the higher the number of repetitions completed during the 1STS. We found no significant effects of the training intervention on performance fatigability, i.e., the differences in rising time, velocity, and power between pre- vs. post-1STS measurements.

The baseline values we reported for the number of repetitions performed during the 1STS was near the 50th percentile (Strassmann et al. 2013), with the training group completing 45 ± 9 repetitions and the control group completing 49 ± 9 repetitions. This moderate baseline performance likely explains why improvements in $1STS_{REP}$ were observed without reaching a substantial ceiling effect, allowing for measurable $16 \pm 14\%$ gains after the training period. No data currently exist on the effects of resistance training on $1STS_{REP}$ in healthy young adults. Nevertheless, in different populations, our findings align with previous studies that reported positive effects of resistance training on $1STS_{REP}$. Zanini et al. (2015) observed a $\approx 8\%$ increase in $1STS_{REP}$ (from 24 ± 4 to 26 ± 6 repetitions) in sedentary patients with moderate respiratory disease following a 3-week resistance training program at $\approx 70\%$ 1-RM. Similar findings have been reported in healthy older adults using the 30-s sit-to-stand test, with training programs lasting 6 (Pinto et al. 2014) to 12 weeks (Ramírez-Campillo et al. 2014; Correa et al. 2016),

leading to a ≈ 20 – 40% increase in the number of repetitions performed over the 30-s period. Interestingly, in our study, participants with higher baseline $1STS_{REP}$ showed smaller improvement in $1STS_{REP}$ after the training period, consistent with previous findings in resistance training literature (Baker and Newton 2006; Mangine et al. 2018). This suggests that individuals with higher baseline muscle performance may have less potential for further improvement.

One original approach of our study was to determine whether improvements in $1STS_{REP}$ were driven by increases in muscle strength, local muscle endurance, or both. We specifically selected performance fatigability as a key metric to inform on local muscle endurance adaptations. In our study, the completion of the 1STS during the initial experimental session resulted in significant fatigability, with over 73% of participants considered as fatigable, consistent with previous findings (Souron et al. 2024b). A correlation has been reported between laboratory-assessed performance fatigability (i.e., the duration a submaximal isometric contraction can be sustained) and local muscle endurance during functional exercises (Justice et al. 2014), suggesting that improving either of these factors should positively influence the other. Although we designed the resistance training program with short rest intervals of 15 s, which could potentially induce high levels of fatigue and acclimate participants to exercising in a fatigued state, we found no improvements in performance fatigability after the training period. This suggests that the training protocol did not sufficiently challenge local muscle endurance or induce the necessary peripheral adaptations to improve fatigue resistance (Egan and Zierath 2013), despite the observed gains in maximal strength. This is not a novel observation, as previous studies have reported that short-term resistance training can increase $1RM$ without necessarily improving performance fatigability. Using the same 3/7 training design, Stragier et al. (2019) reported improvements in performance fatigability (i.e., an increased number of repetitions performed with the same absolute load during a repetitive elbow flexor fatigue protocol), alongside a 22% increase in $1RM$. However, when the fatigue protocol was repeated with the same relative load as before the training period, participants exhibited greater neuromuscular fatigability, performing fewer repetitions after the training period, indicating a higher susceptibility to fatigue (Stragier et al. 2019). Similar findings, emphasizing the absence of improvement in performance fatigability following moderate- to high-intensity resistance training, have been reported in other studies (Izquierdo et al. 2011, 2009). Although the underlying physiological mechanisms were beyond the scope of this study, these results suggest that the gains in muscle strength typically observed following moderate- to high-intensity resistance training may come at the expense of local muscle endurance. Taken together, we suggest that the improvements in $1STS_{REP}$ were likely driven primarily by

strength-related adaptations, particularly increases in muscle power (see below) rather than by changes in local muscle endurance, as performance fatigability did not improve after training. We acknowledge that our study did not include a muscle endurance focused training group or direct laboratory measures of local muscle endurance, limiting our ability to fully disentangle the respective contributions of muscle strength and muscle endurance to $1STS_{REP}$. Future studies could test these hypotheses by including endurance-oriented interventions (e.g., high-repetition, low-load or interval-based protocols) and employing direct measures of local muscle endurance (e.g., sustained isometric contractions to task failure) to determine their specific effect on $1STS_{REP}$ performance.

Despite the lack of change in performance fatigability, we observed significant gains in strength-related metrics, i.e., 1RM, L_0 and A_{line} , and measurements from the *Sit to Stand* app, i.e., rising time, vertical velocity and power. Recent meta-analyses suggest that minimal dose strategies, defined as resistance exercise that falls short of the guidelines recommended by professional exercise organizations but still has the potential to improve muscle strength (Nuzzo et al. 2024a), can increase muscle strength in both the general (Nuzzo et al. 2024a) and resistance-trained population (Androulakis-Korakakis et al. 2020). Our results extend these findings to an untrained young adult population. A 4-week training program consisting of 24 sessions, each with 25 repetitions of the same exercise performed three times per week at 70% of 1RM, provided an optimal stimulus for improving 1RM and the load axis of the load–velocity relationship (i.e., L_0 and A_{line}). However, we did not find correlations between improvements in $1STS_{REP}$ and the gains in 1RM ($r=0.308$, $P=0.077$) or L_0 ($r=0.326$, $P=0.064$). It is important to note that improvements in $1STS_{REP}$ were moderately correlated with gains in A_{line} , which is a representative indicator of an individual's maximal power capacity (Pérez-Castilla et al. 2022, 2021). This suggests that while $1STS_{REP}$ does not fully reflect maximal strength capacity, it does capture the ability to move a load quickly. The significant correlations between improvements in $1STS_{REP}$ and gains in muscle power ($r=0.491$, $P=0.009$), velocity ($r=0.451$, $P=0.015$), and rising time ($r=0.492$, $P=0.009$) from our app during the isolated sit-to-stand maneuver support this assumption. It is important to note that bodyweight remained stable across the training period, minimizing its potential influence as a confounding factor on the results described above. Consistent with our findings, Zanini et al. (2015) reported that improvements in $1STS_{REP}$ were not linked to increases in 1RM during leg extension, but were associated with gains in the 30-s sit-to-stand test in individuals with respiratory condition after a pulmonary rehabilitation program that included resistance training. Similarly, Pinto et al. (Pinto et al. 2014) observed that improvements

in 1RM were related to gains in the 30-s sit-to-stand test in healthy elderly individuals. Thus, shorter-duration sit-to-stand tests may better reflect maximal strength capacity, whereas longer-duration tests are more influenced by endurance factors, reducing the impact of maximal strength gains on overall performance. This hypothesis is supported by our findings, which revealed (i) no relationship between gains in 1RM and improvements in $1STS_{REP}$ and (ii) a moderate correlation between gains in 1RM and increases in muscle power ($r=0.491$, $P=0.043$) derived from the *Sit to Stand* app during a single sit-to-stand execution.

Conclusions

We demonstrated that $1STS_{REP}$ and sit-to-stand-related variables derived from a mobile app are sensitive not only to changes induced by resistance training in chronic populations (Bohannon and Crouch 2019; Andreu-Caravaca et al. 2022), but also in healthy, untrained individuals. These findings highlight the relevance of incorporating $1STS$ assessments in healthy and primary prevention settings to better understand the effects of resistance training protocols on muscle function. However, the relationship between initial $1STS_{REP}$ and post-training improvements raises concerns about a potential ceiling effect in individuals with higher baseline $1STS_{REP}$ than our sample, which was at the 50th percentile.

In general, our findings suggest that improvements in $1STS_{REP}$ were more likely driven by increases in muscle power than by local muscle endurance, although this aspect requires further investigation. The observed associations may provide preliminary indications for future studies aiming to optimize training strategies. However, given the scope and design of the present study, firm conclusions regarding training recommendations cannot be drawn. Future research should specifically address how different training modalities (e.g., power, strength, or endurance oriented) affect sit-to-stand performance, to guide targeted interventions.

Declarations

Conflict of interests The authors have no relevant financial or non-financial interests to disclose.

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