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**Research article**

# Can Changes in Sit-To-Stand Performance Throughout A 30-S Time Interval Be Used as A Marker of Performance Fatigability in Middle-Aged To Older Adults?

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## Abstract

Performance fatigability during the 30-s sit-to-stand (STS) test is not well characterized despite its potential to detect early functional decline. Therefore, this study aimed to quantify temporal changes in power, trunk flexion and movement subphase durations during the 30sSTS, and to examine differences by age and sex. 93 middle-aged adults (50 males and 43 females; mean age 60.5 ± 3.0 years) and 102 older adults (48 males and 54 females; mean age 71.5 ± 5.0 years) performed a 30sSTS. Inertial measurement units (IMUs) mounted over the L4/L5 vertebral level were used to capture sit-to-stand power, trunk flexion and subphase durations in the first and last 10 s. Linear mixed-effects models evaluated temporal changes and group effects. Mean power declined (-11.9 W, d = -0.66), trunk flexion increased (+1.35°, d = 0.42), sit-to-stand duration lengthened and stand-to-sit duration decreased throughout the test (all $p < 0.001$). The within-test decrease in stand-to-sit duration was less pronounced in older compared to middle-aged adults (d = 0.42, p = .039). Older adults generated less power and spent more time in all subphases ($p < 0.05$). Females produced less power and greater trunk flexion ($p < 0.001$). The 30sSTS captures modest performance fatigability; but longer protocols may better reveal clinically meaningful decline. Future research should investigate mobility-limited individuals or examine associations with functional outcomes (frailty, mobility, balance) to provide additional insight.

**Key words:** Sit-to-stand test, lower-limb power, healthy aging, performance fatigability, functional performance.

## Introduction

Fatigability - the tendency to develop fatigue during activity - is a key marker of age-related functional decline. Greater fatigability is linked to mobility loss, inactivity and mortality (Glynn et al., 2022; Paris et al., 2022; Qiao et al., 2023; Schrack et al., 2020; Simonsick et al., 2016). When measured objectively, it is termed performance fatigability, reflecting exercise-induced declines in force or power (Qiao et al., 2023) arising from both neural and muscular mechanisms that vary with task demands (Hunter, 2018).

The 30-s sit-to-stand (30sSTS) test is a widely used measure of lower-limb function. Muscle function indicators, such as total repetitions and mean power output, decline from midlife (Alcazar et al., 2021b) and predict balance impairment, mobility limitation, frailty and mortality (Alcazar et al., 2021a; 2021b; Cheng et al., 2014; Garcia-Aguirre et al., 2025; Van Roie et al., 2019). Different technological approaches enable detailed analyses of STS dynamics, each offering distinct measurement capabilities. Linear encoders capture movement displacement over time and have been validated specifically for assessing STS velocity and STS power in older adults (Lindemann et al., 2015; Lindemann et al., 2016; Coelho-Júnior et al., 2024). Force plates and repetition-based power estimations, by contrast, quantify the forces and power exerted during the task rather than the movement itself, and have similarly been applied to assess STS performance (Baltasar-Fernandez et al., 2021). Inertial measurement units (IMUs) extend these capabilities by not only capturing movement velocity and STS power, but also discrete STS subphases (i.e., sitting, sit-to-stand, standing, and stand-to-sit) and trunk kinematics throughout the task (Meulemans et al., 2023). This kinematic detail allows IMUs to reveal compensatory movement strategies that the other approaches cannot easily detect. For instance, Meulemans et al. (2023) showed that mobility-limited older adults exhibit greater trunk flexion and prolonged static phases during STS tasks, which are strategies that facilitate task completion but reduce movement efficiency and speed (Lin and Lee, 2022; Papa and Cappozzo, 2000). Collectively, these findings suggest that IMU-based assessments may be particularly well suited to detecting temporal changes in STS performance across a 30-s timeframe, potentially serving as markers of performance fatigability.

As fatigability is a key marker of functional decline (Glynn et al., 2022; Schrack et al., 2020; Simonsick et al., 2016) yet remains unquantified in the 30sSTS test, this study used IMU-derived power, trunk flexion and subphase duration metrics to assess performance fatigability. Temporal changes across the 30-s period were analyzed to characterize fatigue-related declines and movement adaptations by age and sex. We hypothesized that older adults would show greater performance fatigability than middle-aged adults, while analyses regarding sex differences were considered exploratory.

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# Methods

## Participants

This cross-sectional study included 93 middle-aged (55 - 64 years; 46% female) and 102 older adults ( ≥ 65 years; 53% female). All participants were community-dwelling, able to walk independently and to stand up from a chair independently without arm assistance. Exclusion criteria were unstable cardiovascular disease, dementia, recent surgery, acute infection, fever and musculoskeletal lower-limb injury. Participants provided written informed consent. The study was approved by the Ethics Committee Research of UZ/KU Leuven (S62540) in accordance with the Declaration of Helsinki.

## Outcome measures

*Anthropometrics.* Height and weight were measured using a stadiometer and calibrated scale, and body mass index (BMI, kg/m$^2$) was calculated.

*Sit-to-stand test.* Participants completed two familiarization trials of the 5-repetition STS before one 30sSTS trial. These familiarization trials served to accustom the participants with the correct technique of the STS test while avoiding inducing fatigue, and to ensure maximal performance from the first repetition onwards in the 30sSTS. Participants began seated in an armless chair (seat height: 0.46 m), back touching the rest and arms crossed over the chest. Following a verbal countdown (“3 - 2 - 1, start”), participants stood up and sat down as many times as possible within 30 seconds, fully extending hips and knees each time, while receiving standardized verbal encouragement throughout the test.

A body-fixed IMU (DynaPort Move Test, McRoberts, The Hague, NL) was positioned at the lumbar spine over the L4/L5 vertebral level using an elastic belt. For each STS cycle, the following outcomes were extracted (Meulemans et al., 2023): (1) durations of four subphases (sitting, sit-to-stand, standing, stand-to-sit; in s), (2) trunk flexion range (°), defined as angular displacement from upright sitting to peak flexion during the sit-to-stand phase; and (3) absolute mean STS power (W) during sit-to-stand. Absolute STS power was derived by the manufacturer’s software (DynaPort MoveTest, McRoberts) from IMU-based kinematics as instantaneous power, calculated as body mass × (vertical acceleration + 9.81 m/s$^2$) × vertical velocity × cos(angle between the vertical velocity and vertical force vector) (Meulemans et al., 2023). The first and last repetitions were excluded, and a single mean value was calculated for all completed repetitions within the first and last 10-second windows for every participant.

Additionally, to categorize participants into groups based on their fatigability levels, the relative change in power output between these periods was calculated. Participants were classified as having no ( ≤ 5%), limited (5 - 10%), modest (10 - 20%) or severe ( > 20%) fatigability, as proposed by Lindemann et al. (2016).

## Statistical analyses

Statistical analyses were performed in R (version 4.2.2). Baseline differences between groups were tested by two-way ANOVAs. Intra-test changes were examined using linear mixed-effects models with time (first vs. last 10 s), age group (middle-aged vs. older) and sex as fixed effects, and participant ID as a random intercept to account for repeated measures. Residual normality was assessed through Q-Q plots, histograms and Shapiro-Wilk tests.

Non-normally distributed variables (sitting, sit-to-stand, standing, stand-to-sit phases) were log-transformed prior to analysis. Model effects are reported as exponentiated coefficients (exp[β]), while means and standard deviations are reported on the original scale for interpretation. Time by age group and time by sex interaction terms were analyzed in a secondary analysis using linear mixed-effects modeling. Group differences in fatigability categorization were evaluated using $\chi^2$ tests for sex and Fisher’s exact tests for age group. Significance level was set at $p < 0.05$. Effect sizes were expressed as Cohen’s d and calculated by dividing the fixed-effect estimate (beta) from each linear mixed model by the model residual standard deviation. For log-transformed outcomes, d was based on the log-transformed coefficient.

# Results

Table 1 presents the baseline characteristics of the participants.

Figure 1 presents the age- and sex-specific changes in absolute mean STS power between the first and last 10s of the 30sSTS. Absolute mean STS power declined significantly from the first to the last 10 s (β = -11.86 W, 95% CI -15.44, -8.28], d = -0.66, p < 0.001). Older adults produced less absolute power than middle-aged adults (β = -26.15 W, 95% CI [-42.00, -10.30], d = -1.45, p = 0.001). Females produced significantly less absolute power than males (β = -127.51 W, 95% CI [-143.35, -111.67], d = -7.07, p < 0.001). Interaction terms were not significant (all p > 0.05).

**Table 1. Baseline characteristics of participants (mean ± standard deviation)**

| Parameters | | Middle-aged Males (N = 50) | Middle-aged Females (N = 43) | Older adults Males (N = 48) | Older adults Females (N = 54) | Significance level (p-value) * Age | Significance level (p-value) * Sex |
|---|---|---|---|---|---|---|---|
| **Age (years)** | | 61.7 ± 2.6 | 59.1 ± 3.0 | 71.5 ± 4.8 | 71.4 ± 5.3 | < .001 | .029 |
| **Body mass (Kg)** | | 81.2 ± 11.9 | 67.5 ± 11.5 | 83.0 ± 10.0 | 66.5 ± 11.7 | .724 | < .001 |
| **Height (cm)** | | 176.7 ± 6.5 | 164.7 ± 4.9 | 174.9 ± 5.9 | 161.3 ± 6.3 | < .001 | < .001, |
| **BMI (Kg/m$^2$)** | | 26.0 ± 3.5 | 24.9 ± 4.3 | 27.1 ± 3.0 | 25.6 ± 4.3 | .138 | .015 |
| **30sSTS** | **Repetitions (#)** | 18.0 ± 2.4 | 18.0 ± 2.2 | 16.4 ± 2.3 | 15.5 ± 2.6 | < .001 | .175 |
| | **Relative power (W/Kg)** | 4.25 ± 1.12 | 3.24 ± 0.40 | 3.84 ± 0.66 | 2.87 ± 0.63 | < .001 | < .001 |
| | **Allometric Power (W/m$^2$)** | 109.0 ± 21.9 | 80.5 ± 15.8 | 103.9 ± 19.5 | 72.0 ± 13.0 | < .001 | < .001 |

BMI = body mass index; 30sSTS = 30-second sit-to-stand test. * P-values are from two-way ANOVA with age group and sex as fixed factors.

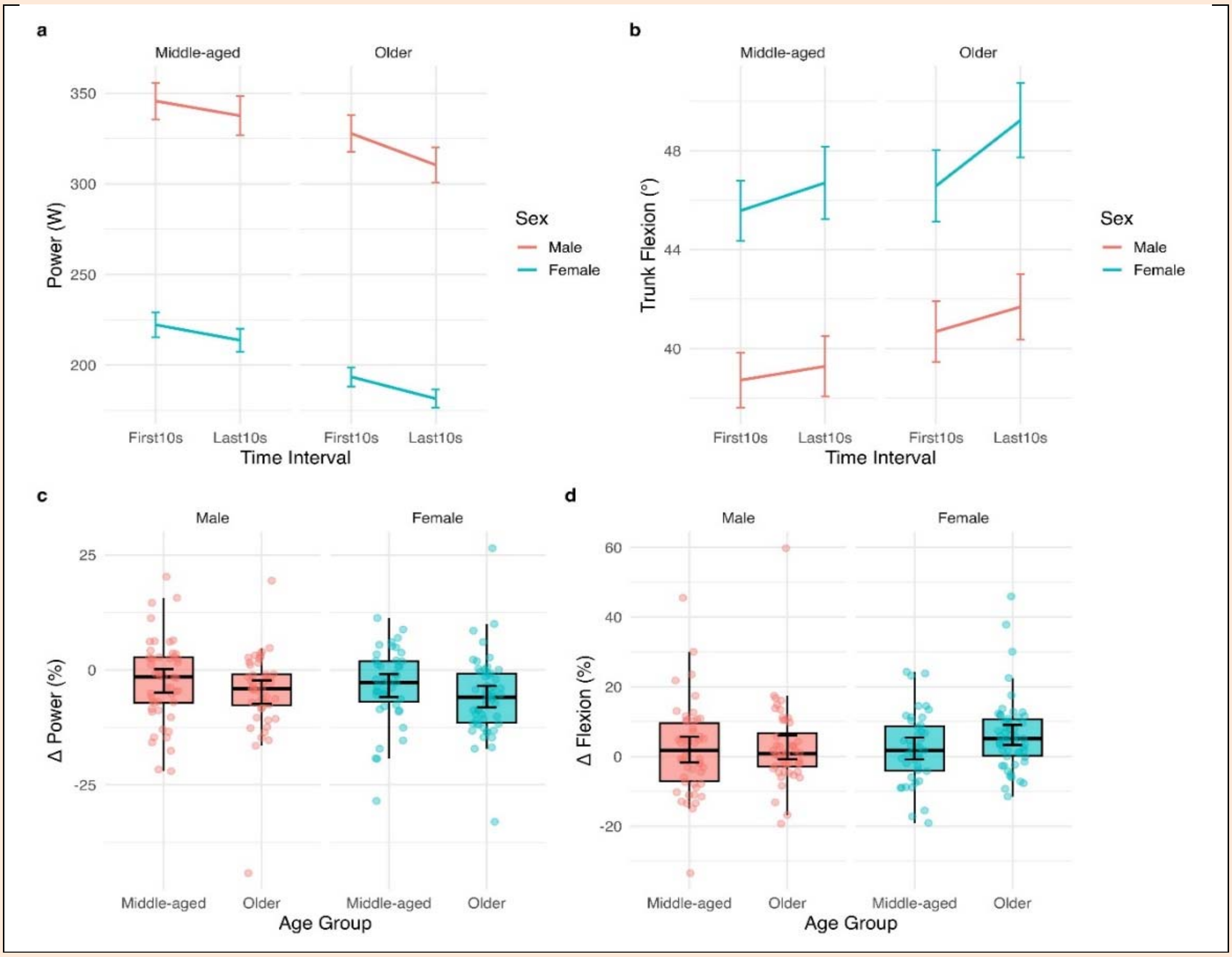


**Figure 1. Absolute (upper panels) and relative (lower panels) changes in mean power and trunk flexion during the 30-s sit-to-stand test (30sSTS).** Panels a and b show absolute changes in mean power (a) and trunk flexion (b) from the first to the last 10 s of the 30STS for middle-aged and older males and females. Panels c and d show relative (%) changes in mean power (c) and trunk flexion (d). Error bars represent standard errors. Bars indicate group means ± standard deviations with individual data points overlaid; antennae represent standard errors. Mean power significantly declined over time and was lower in females and older adults compared with males and middle-aged adults, respectively (all p < 0.05), whereas trunk flexion significantly increased over time and was greater in females than in males (all p < 0.05). No interaction effects were detected.

Figure 2 visualizes the categories of power fatigability separately for age and sex groups: 63% of middle-aged and 50% of older adults showed no or limited fatigability ( < 5%); 24.5% of older adults and 12.9% middle-aged adults showed modest fatigability (10 - 20%). Among the older adults with modest fatigability, 16 out of 25 (64.0%) were females. The distribution between no or limited fatigability and modest fatigability was not significantly different between age ($p = 0.136$), nor between sexes ($p = 0.683$).

## Trunk flexion

Figure 2 presents the age- and sex-specific changes in trunk flexion between the first and last 10s of the 30sSTS. Trunk flexion increased toward the end of the 30sSTS ($\beta = 1.35°$, 95% CI [0.72, 1.99], $d = 0.42$, $p < .001$). There was no difference in trunk flexion between older and middle-aged adults ($p = 0.122$). Females exhibited greater trunk flexion than males across all repetitions ($\beta = 6.93°$, 95% CI [4.41, 9.45], $d = 2.17$, $p < 0.001$). Interaction terms were not significant ($p > 0.05$).

## Subphase durations

Figure 3 illustrates the durations (s) of the subphases separated by age and sex. The duration of the sit-to-stand phase (upward movement) increased from the first to the last 10 s ($\exp[\beta] = 1.04$, 95% CI [1.03, 1.05], $d = 0.92$, $p < 0.001$), and was longer in older compared to middle-aged adults ($\exp[\beta] = 1.13$, 95% CI [1.08, 1.18], $d = 2.76$, $p < 0.001$) and in females compared to males ($\exp[\beta] = 1.07$, 95% CI [1.02, 1.12], $d = 1.58$, $p = 0.003$). Stand-to-sit duration decreased from the first to the last 10 s ($\exp[\beta] = 0.98$, 95% CI 0.97, 0.99], $d = -0.39$, $p < 0.001$) and was longer in older compared to middle-aged adults ($\exp[\beta] = 1.14$, 95% CI [1.09, 1.20], $d = 2.39$, $p < 0.001$). Sitting and standing durations did not change over time ($p = 0.638$ and $p = 0.826$, respectively), but both were longer in older compared to middle-aged adults (sitting: $\exp[\beta] = 1.22$, 95% CI [1.09, 1.37], $d = 0.99$, $p < 0.001$; standing: $\exp[\beta] = 1.19$, 95% CI [1.05, 1.34], $d = 0.88$, $p = 0.005$). The stand-to-sit duration showed a time-by-age interaction effect ($\exp[\beta] = 1.02$, 95% CI [1.00, 1.05], $d = 0.42$, $p = 0.039$), indicating that the within-test decrease in duration was less pronounced in the older compared to the middle-aged adults. All other interaction terms were not significant (all $p > 0.05$).

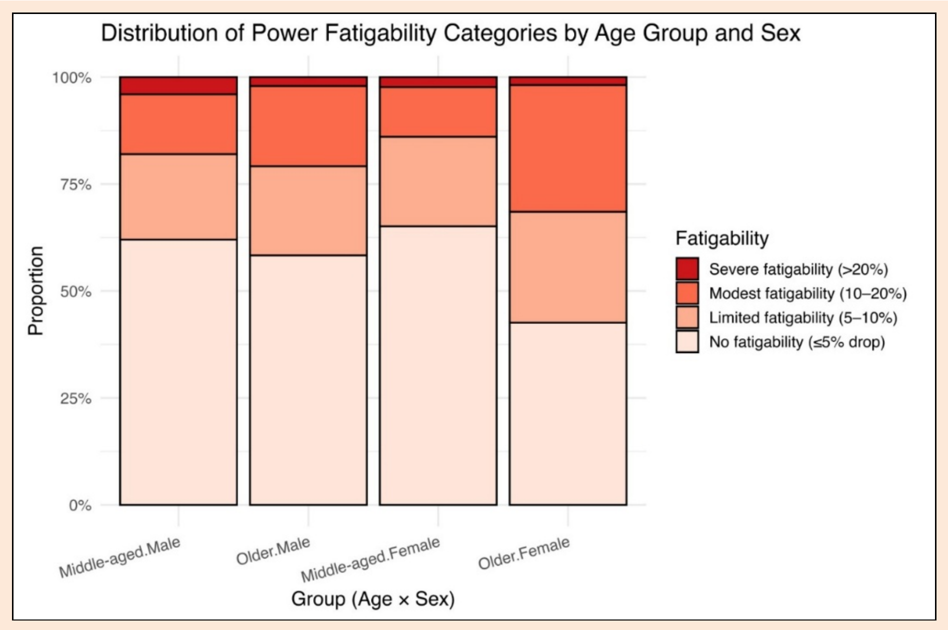


**Figure 2. Distribution of power fatigability categories (≤5%, 5–10%, 10–20%, >20% decline) for middle-aged and older adults.**

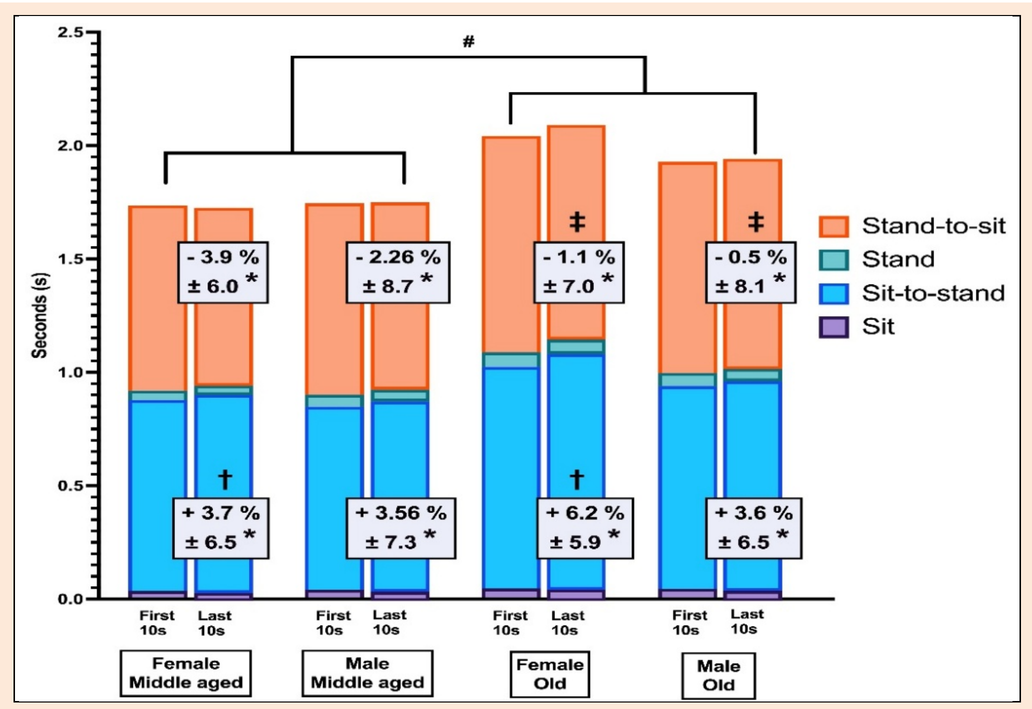


**Figure 3. Mean durations of the four sit-to-stand sub-phases during the first and last 10s of the 30-second sit-to-stand test by age group and sex.** Bars represent mean phase durations (s); mean percentage change ± SD is displayed on the Sit-to-Stand and Stand-to-Sit bars, as those changes over time were significant at $p < 0.05$ (indicated with *); #all subphase durations were significantly longer in older versus middle-aged adults ($p < 0.05$); †Sit-to-Stand duration was significantly longer in females versus males ($p < 0.05$). ‡ a significant time-by-age interaction was observed for stand-to-sit duration ($p < 0.05$).

## Discussion

This study examined IMU-derived sit-to-stand power output, trunk flexion and subphase durations to evaluate performance fatigability and movement adaptations across the 30-s period in relation to age and sex. The results show consistent fatigue-related shifts across mechanical, kinematic and temporal domains. However, no age- or sex-related differences in temporal patterns occurred, except for a less pronounced within-test decrease in stand-to-sit duration in older compared to middle-aged adults.

Across participants, changes over time were significant for all 30sSTS parameters except sitting and standing duration. The observed decline in absolute mean STS power (-11.89 W) aligns with the expected reduction in neuromuscular output during repeated high-intensity movements. The observed increase in trunk flexion range (1.35°) is an expected compensatory strategy for maintaining task performance when power out decreases (van der Kruk and Geijtenbeek, 2024; van der Kruk et al., 2022). The shorter stand-to-sit phase may reflect diminished eccentric control due to neuromuscular fatigue, or a compensatory strategy to accelerate the descent and partially counterbalance the time lost during rising. It is important to note that, while these changes were significant, the observed changes were small and therefore likely of limited functional relevance in well-functioning adults.

When comparing middle-aged to older adults, absolute power and subphase durations were lower at older age, while older adults showed a less pronounced reduction in stand-to-sit duration over time. Apart from this, all other markers of performance fatigability over time were not different between age groups. A possible explanation is the high functional capacity of both groups. Although direct comparisons with previous studies are limited by methodological differences between IMU-based and formula-derived estimates (Meulemans et al., 2023), relative power values (3.79 $W \cdot kg^{-1}$ in middle-aged and 3.33 $W \cdot kg^{-1}$ in older adults) were within reported normative ranges (Alcazar et al., 2021b). Moreover, participants demonstrated high functional performance, with average repetition counts slightly exceeding normative values reported by Alcazar et al. (2021b) for both men (16.4 vs. 15.6 repetitions) and women (15.5 vs. 14.6 repetitions). Longer STS protocols, such as the 60 or 90-s STS, may therefore be more sensitive for detecting performance fatigability in well-functioning older adults, as demonstrated by Lindemann et al. (2016), who observed progressive declines in STS performance during 90-s STS in older women using linear encoders. Another approach to increase the volume of STS cycles, hypothesized to induce more fatigue, might be the use of multiple sets of STS bouts within a single session.

Regarding differences between sex groups, females produced less absolute power, showed greater trunk flexion and required more time for the STS movement than males. This is consistent with the established sex-related differences in lower-limb strength and power (Hunter, 2016). While females often are considered more fatigue resistant in isometric tasks, this difference tends to be diminished in dynamic demands (Hunter, 2016). Therefore, the absence of sex differences in markers of performance fatigability in this study aligns with the current body of literature, given the dynamic nature of the STS movement.

The strength of this study lies in its integration of mechanical, kinematic and temporal analyses of performance fatigability in a large, age-diverse sample. However, some limitations to this study need to be considered. Firstly, the sample included only well-functioning, community-dwelling adults, limiting generalizability to mobility-limited populations. Although the STS has been widely applied in these mobility-limited populations, within- test changes in performance remain poorly understood and their association with clinical outcomes should be investigated in future studies. Secondly, we did not account for physical activity levels nor comorbidities, which may have influenced age-group comparisons. Thirdly, only a single 30s STS trial was performed per participant, excluding the potential to assess intra-session reliability and trial-to-trial fluctuations. Therefore, it remains unclear whether our observed changes throughout the 30s timeframe reflect true fatigue. A more direct assessment of neuromuscular fatigue post the 30sSTS test, e.g. by using maximal voluntary contractions, would add value to interpret these changes in future research. Additionally, examining the relationship between fatigability and functional outcomes such as mobility, balance or frailty would provide further insight into its clinical and functional significance.

## Conclusion

In conclusion, significant but small within-test changes in sit-to-stand power output, trunk flexion and subphase durations can be detected throughout the 30sSTS in healthy middle-aged and older adults, which may be indicative of performance fatigability. However, no differences in the within-test changes over time were apparent between age groups and sexes, except for a less pronounced reduction in stand-to-sit duration in older compared to middle-aged adults.


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## Key points

- This study provides the first detailed description of performance fatigability during the 30sSTS using IMU-based measures.
- The 30sSTS can detect performance fatigability; however, observed differences are small in healthy adults.
- Longer STS protocols may be needed to reveal clinically meaningful fatigability in healthy populations.

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