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# Biomechanical analysis of movement time and center of pressure during single-leg and double-leg sit-to-stand in healthy adults

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**ABSTRACT**

**Background:** The sit-to-stand (STS) task is a fundamental movement integral to daily activities and is widely used as a functional test to evaluate lower limb strength, balance, and postural control across various populations. However, limited literature provides biomechanical analysis comparisons between traditional double-leg STS tasks and single-leg STS tasks.

**Objective:** This study aimed to compare muscle strength, movement times, and center of pressure (COP) variables across three STS conditions: single-leg STS on the dominant limb, single-leg STS on the non-dominant limb, and double-leg STS.

**Materials and methods:** Twenty healthy participants (10 males and 10 females; 21.60±1.14 years old) participated in a cross-sectional study. Maximal voluntary isometric contraction of the knee extensors and hip abductors was assessed for both the dominant and non-dominant limbs. Participants performed the three STS testing conditions on the Zebris FDM pressure plate. Movement time and COP outcome variables (sway area, total path length, velocity, and path length in anteroposterior and mediolateral directions) were recorded and analyzed across the three STS tasks. A paired t-test was used to compare the means of the primary outcome variables within groups. A one-way repeated measures ANOVA was conducted to assess outcome differences among the testing conditions, with significance set at $p<0.05$.

**Results:** Findings indicated no significant difference in knee extensor or hip abductor muscle strength between the dominant and non-dominant limbs. Movement times for the single-leg STS tasks on both limbs were significantly longer than for the double- leg STS task ($p<0.001$), with no difference between dominant and non-dominant limbs. Additionally, COP variables (sway area, total path length, mean velocity, and mediolateral path length) were significantly lower in the single-leg STS tasks on both limbs compared to the double-leg STS task (all $p<0.001$), with no differences observed between dominant and non-dominant limbs.

**Conclusion:** Compared to double-leg STS tasks, single-leg STS tasks are associated with longer movement times and reduced COP measures. These findings provide preliminary reference values for STS tasks and suggest that the single-leg STS may serve as a potentially useful tool for assessing balance impairments and functional mobility. Further research is required to validate its sensitivity in pathological populations.

## Introduction

The sit-to-stand (STS) task is a fundamental movement integral to daily activities and crucial for maintaining functional independence. This task involves transitioning from a seated to a standing position, requiring coordinated activation of trunk and lower limb muscles

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while maintaining balance throughout the movement period.[1,2] As the STS movement is an essential functional task, it is widely utilized as a functional movement test to evaluate lower limb strength, balance, and postural control. Specifically, the STS task is frequently employed in clinical and rehabilitation settings to evaluate functional mobility and monitor disease progression or treatment effectiveness for lower limb injuries and age-related conditions.[3]

The STS task is a standard component of various biomechanical studies that provides insights into neuromuscular control and movement efficiency.[4] This is mainly due to the task's reliance on lower limb strength, particularly the core, hip, and knee extensor muscles, which are critical for ensuring task completion and movement smoothness.[5] Research indicates that biomechanical outcome variables associated with the STS task, such as movement time, power, and acceleration, are closely linked to the strength of these muscle groups, highlighting the importance of core and lower limb function in performing this task efficiently. A study by Alcazar et al.[6] found a strong correlation between acceleration parameters measured from the 30-second STS test and bilateral lower limb muscle strength. Stagsted *et al*.[7] also reported that lower extremity muscle strength, measured through chair rise and leg press tests, was associated with movement time on the 5-times STS test.

A previous study examined the biomechanical differences between double-leg and single-leg STS tasks, particularly in comparing dominant and non-dominant limbs.[8] Double-leg STS distributes the load evenly across both legs, resulting in more excellent stability and reduced postural sway.[9] In contrast, single-leg STS tasks pose more significant challenges to balance, particularly on the non-dominant leg, which often exhibits reduced movement control, longer movement times, and more significant displacement of the center of pressure (COP).[10] These differences highlight variations in muscle strength and coordination between the limbs. Specifically, the muscle strength and power disparity between the dominant and non-dominant legs influences task performance.[11] This suggests that functional movements that involve the dominant and non-dominant legs may yield different outcomes, as muscle strength in different muscle groups plays a significant role in movement quality during functional tasks. Thus, it is essential to note that differences in muscle strength between the dominant and non-dominant limbs in sagittal plane movements, such as hip and knee flexion/extension or ankle dorsiflexion, and frontal plane movements, such as hip abduction/adduction, may directly affect the STS task.[12]

Based on recent literature, previous studies demonstrated that strength differences, especially in the lower limb, directly impact movement performance, such as the STS task. However, there is limited evidence comparing the biomechanics of single-leg and double-leg STS tasks using movement time and COP outcomes, a commonly used kinetic variable in biomechanics for analyzing body sway, providing insights into an individual's ability to control body movement and lower limb function,[13,14] among young adults. Therefore, this study aimed to compare muscle strength, movement times, and COP variables across three STS conditions: single-leg STS on the dominant limb, single-leg STS on the non-dominant limb, and double-leg STS. It is hypothesized that the non-dominant limb would show longer movement times and greater COP displacement than the dominant limb, with both single-leg tasks performing worse than the double-leg STS.

## Materials and methods

### *Study design and participants*

A cross-sectional study design with single-session data collection was employed in this study. Participants were recruited through flyers and online platforms. Data were collected at the Biomechanics Laboratory, Department of Physical Therapy, Faculty of Associated Medical Sciences, Chiang Mai University, Chiang Mai, Thailand. The sample size was calculated using G*Power version 3.1.9.6 (Universität Kiel, Germany), based on a previous study that analyzed differences between two dependent means of the time required to complete a one-repetition single-leg STS.[15] A total of 20 participants was deemed necessary, considering an expected moderate effect size (0.6), an alpha level of 0.05, and a statistical power of 0.80.

Twenty male and female participants were screened and recruited into the study based on predefined inclusion and exclusion criteria (Table 1). The inclusion criteria required healthy participants aged 18 to 25 years, with a normal body mass index (BMI) of 18.5-22.9 and the ability to independently perform the STS movement for both dominant and non-dominant limbs.[16] Exclusion criteria included participants with vision problems, a history of diagnosed neurological disorders such as stroke or brain injury, or other conditions impairing the function of the vestibular, somatosensory, or visual systems. Participants with conditions affecting their ability to stand, walk, or maintain postural balance during single-leg standing and those experiencing pain or lower limb deformities that limit movement were also excluded. All participants were informed about the testing procedures and provided written informed consent before participation. The study was approved by the Research Ethics Committee of the Institutional Review Board (approval number: AMSEC-67EX-001).

**Table 1**. Characteristics of participants.

| | Mean±SD |
|---|---|
| N | 20 |
| Male: female | 10:10 |
| Age (years) | 21.60±1.14 |
| Height (m) | 1.64±0.06 |
| Body weight (kg) | 56.31±5.88 |
| Body mass index (kg/m$^2$) | 20.95±1.42 |

***Procedures***

The testing session began with participants providing basic demographic information and filling in the Waterloo Footedness Questionnaire (revised version) to indicate the dominant and non-dominant limbs.[17] Maximal voluntary isometric contraction (MVIC) was then assessed for the hip abductors and knee extensors. Following this, participants completed the STS test under three conditions: single-leg STS on the dominant limb, single-leg STS on the non-dominant limb, and double-leg STS. The order of conditions was randomly performed. Participants were allowed two to three practice trials for each condition before testing. Each condition was conducted in three trials, with a 2-minute rest between trials to prevent neuromuscular fatigue. Before the test, participants were instructed to avoid strenuous exercise, alcohol, caffeine, and any medication that could influence task performance within 24 hours of the session.

A handheld dynamometer (Lafayette, IN, USA) was used to measure the muscle strength of the hip abductors and knee extensors. For the hip abduction test, participants lay supine on a treatment bed, with the dynamometer placed laterally on the knee, 3 centimeters above the knee joint line. Participants performed an MVIC of the hip abductors in both limbs for 5 seconds, with two repetitions and a one-minute rest between trials. For the knee extension test, participants were seated comfortably on a chair, with the dynamometer positioned anteriorly on the shank, 3 centimeters above the ankle joint. Knee extensor MVIC was assessed in both limbs for 5 seconds, again with two repetitions and a one-minute rest between trials. The average values from each limb were calculated to represent muscle strength. One examiner administered muscle strength measurements for all participants. Test-retest reliability, assessed using the intraclass correlation coefficient ($ICC_{3,1}$) before the actual testing, demonstrated good to excellent reliability (ICC 0.788-0.974) for both muscles across both limbs.

In the single-leg STS test, participants were instructed to sit upright on an adjustable chair without leaning on the backrest, with their arms crossed over the chest. The foot of the testing leg, either dominant or non-dominant, was positioned at the center of the Zebris FDM pressure platform (FDM2, Zebris Medical GmbH, Germany), with data recorded using the Zebris FDM Software Suite. Participants were positioned with approximately 100 degrees of knee flexion, ensuring that the ankle was positioned behind the knee. The non-testing leg was lifted slightly off the ground, ensuring it did not move forward, backward, or touch the floor during the STS task. Participants were then instructed to stand up from the chair on a single leg using their lower limb strength, keeping their body upright while standing, and then sit back down. If the non-testing leg touched the ground or the participant used their arms to assist the movement, the trial was deemed unsuccessful, and they were asked to repeat the task until a successful trial was completed. Participants performed three successful trials on each testing leg (Figure 1).

***Figure 1**. Single-leg sit-to-stand testing task.*

In the double-leg STS test, participants were instructed to sit upright on an adjustable chair without leaning on the backrest, with their arms crossed over the chest. Their feet were positioned shoulder-width apart at the center of the FDM pressure platform. Participants were positioned with approximately 100 degrees of knee flexion, ensuring the ankles were placed behind the knees. They were then instructed to stand up from the chair using the strength of both lower limbs, maintain an upright posture while standing, and then sit back down. If participants compensated for their movement or used their arms to assist, the trial was deemed unsuccessful, and they were asked to repeat the task until a successful trial was completed (Figure 2).

***Figure 2**. Double-leg sit-to-stand testing task.*

***Data reduction***

The movement time for each trial was measured by the stopwatch, calculated from the moment the participant's buttocks left the chair until full contact was made again upon sitting. The pressure plate was set to a sampling frequency of 100 Hz. COP variables, including COP sway area, COP total path length, COP velocity, COP path length in the anteroposterior direction, and COP path length in the mediolateral direction, were calculated using the Zebris FDM Software Suite.

***Statistical analysis***

Descriptive statistics were used to report the mean, standard deviation (SD), and 95% confidence interval (CI) for all outcome variables. Data distribution was assessed using the Shapiro-Wilk test, which confirmed that all data were normally distributed. Accordingly, a paired t-test was employed to compare the means of the primary outcome variables within groups, and a one-way repeated measures ANOVA was conducted to compare the mean values across the three different STS conditions. When the ANOVA identified significant differences, pairwise comparisons using the least significant difference test (LSD) were performed to determine the specific conditions with significant differences. The effect size was estimated using partial eta-squared ($\eta^2_p$), where values less than 0.01 indicated a small effect size, values between 0.01 and 0.06 indicated a medium effect size and values greater than 0.06 indicated a large effect size. Statistical analyses were performed using SPSS (version 17, SPSS Inc., USA), with a significance level of $p \leq 0.05$.

## Results

The present study included 20 participants. Table 1 presents the demographic characteristics of all participants.

The strength of the knee extensor and hip abductor muscles for both the dominant and non-dominant legs is presented in Table 2. Statistical analysis indicated no significant differences in the strength of the knee extensor and hip abductor muscles between the dominant and non-dominant legs.

The results indicated a significant difference in the duration of the STS task across the three different conditions ($F(2,38) = 14.316$, $p<0.001$, $\eta^2_p=0.430$). Specifically, the duration of the single-leg STS on both the dominant and non-dominant limbs was significantly longer than that of the double-leg STS (all $p<0.001$). However, no significant difference was observed in the duration between the single-leg STS on the dominant and non-dominant limbs (Table 3).

**Table 2**. Muscle strength of knee extensor and hip abductor muscles.

| | Dominant limb (mean±SD) | Non-dominant limb (mean±SD) | $t_{19}$ | *p* |
|---|---|---|---|---|
| Knee extensor (N) | 192.70±43.74 (173.65-211.75) | 199.66±40.21 (182.04-217.28) | -1.414 | 0.173 |
| Hip abductor (N) | 173.09±27.07 (161.23-184.95) | 172.21±28.93 (159.53-184.89) | 0.306 | 0.763 |

**Table 3**. A comparative analysis of movement time and center of pressure during single- and double-leg sit-to-stand tasks.

| | Single-leg STS on dominant limb (Mean±SD) | Single-leg STS on non-dominant limb (Mean±SD) | Double-leg STS (Mean±SD) | *F* | *P* | $\eta^2_p$ |
|---|---|---|---|---|---|---|
| Time (sec) | 1.51±0.35 * (1.36-1.66) | 1.49±0.38 ** (1.32-1.66) | 1.15±0.13 (1.09-1.21) | 14.316 | <0.001# | 0.430 |
| COP sway area (mm²) | 5447.38±1581.75* (4754.16-6140.60) | 5340.35±1822.66* (4541.55-6139.15) | 16950.43±6933.84 (13911.60-19989.26) | 54.180 | <0.001# | 0.740 |
| COP total path length (mm) | 1019.54±234.98* (916.56-1122.52) | 999.52±165.11* (927.16-1071.88) | 1749.26±468.14 (1544.09-1954.43) | 41.097 | <0.001# | 0.684 |
| COP velocity (mm/sec) | 226.20±55.85* (201.72-250.67) | 224.67±56.47* (99.92-249.42) | 443.11±133.70 (384.51-501.71) | 63.253 | <0.001# | 0.769 |
| COP path length in the mediolateral direction (mm) | 38.91±9.65* (34.68-43.14) | 38.14±10.65* (33.47-42.81) | 111.46±30.21 (98.22-124.70) | 15.618 | <0.001# | 0.251 |
| COP path length the anteroposterior direction (mm) | 177.20±23.63 (166.84-187.56) | 174.87±27.28 (162.91-186.83) | 183.19±35.92 (167.45-198.93) | 0.829 | 0.444 | 0.042 |

*Note: *significant differences with double-leg STS condition (p<0.001), **significant differences with double-leg STS condition (p<0.01), #significant differences between the sit-to-stand conditions (p<0.001), STS: sit-to-stand, sec: second, mm: millimeter.*

There were statistically significant differences in the COP area (F(2,38)=14.316, *p*<0.001, $\eta^2_p$=0.430), COP total path length (F(2,38)=41.097, *p*<0.001, $\eta^2_p$=0.684), COP average velocity (F(2,38)=63.253, *p*<0.001, $\eta^2_p$=0.769), and the length of the COP in the anteroposterior direction (F(2,38)=15.618, *p*<0.001, $\eta^2_p$=0.251). Pairwise comparisons indicated that the values for the single-leg STS on both limbs were significantly lower than those recorded during the double-leg STS test (*p*<0.001). In contrast, no significant differences were found in COP area, COP total path length, COP average velocity, or the length of the COP in the anteroposterior direction between the dominant and non-dominant sides (Table 3). Furthermore, there were no differences in the length of the COP in the mediolateral direction between the dominant, non-dominant sides, and double-leg STS.

## Discussion

This study compared movement time and COP variables during three STS tests: single-leg STS on the dominant limb, single-leg STS on the non-dominant limb, and double-leg STS. Significant differences were detected between the single-leg STS (for both limbs) and the double-leg STS tasks for all outcomes, except the COP path length in the anteroposterior direction. However, the results did not support our hypothesis, as no significant differences were observed in movement time and COP between the dominant and non-dominant limbs.

Movement time is a commonly used variable to assess overall physical ability in performing STS movements.[18] In this study, we found that the movement time from a seated position in the single-leg STS—both with the dominant and non-dominant legs—was longer than that of the double-leg STS test. This finding is consistent with the study's hypothesis. It aligns with previous research by Thongchoomsin *et al*., who reported that the time spent raising the body from a chair and returning to a seated position during a 5-repetition double-leg STS test was, on average, 3.36 seconds longer for the single-leg STS.[8] In the present study, the single-leg STS on the dominant leg took 0.34 seconds longer, while the single-leg STS on the non-dominant leg took 0.36 seconds longer than the double-leg during the one-time STS test. The difference in movement time can be attributed to the larger base of support (BOS) provided by both feet during the double-leg STS, in contrast to the more limited BOS of a single foot during the single-leg STS.[19] Additionally, rising from a seated position using both legs is a familiar and natural daily movement, facilitating a more fluid and smooth motion. From a biomechanical perspective, performing the single-leg STS requires using one leg's muscle strength to counteract the entire body weight. Although the body weight remains constant, only the supporting leg muscles are engaged to generate the necessary force to stand up and return to sitting.[19,20] This increased demand for a single limb resulted in slower movement and, consequently, a longer completion time for the single-leg STS compared to the double-leg STS.

No statistically significant difference was found between the two conditions when comparing movement times in the single-leg STS test on the dominant and non-dominant limbs. This lack of difference may be attributed to the finding that the strength of our participants' knee extensor and hip abductor muscles in both legs did not show significant variation. These results are inconsistent with previous research, which identified differences in muscle strength between the dominant and non-dominant limbs regarding the knee extensors and flexors in healthy participants.[11] Additionally, the researchers maintained consistent testing postures, including knee and hip angles, across all test formats, resulting in no differences in the angular movement of the trunk and lower limb joints between the two conditions. It was supported by the study by Steingrebe *et al*., who reported no differences in knee joint moments and loading when rising from a seated position using either the dominant or non-dominant limb, noting that only low chair heights contributed to increased shear forces on the knee.[21]

Regarding the COP outcomes, the COP sway area and total path length serve as indicators of the overall area of the COP and the total distance the COP travels during the STS movement.[13] These COP variables evolve as the STS test is performed. The path length in the anteroposterior direction (the length of the COP major axis) corresponds to the direction of the body's movement when weight is transferred forward during the standing-up phase. In contrast, the path length in the mediolateral direction (the length of the COP minor axis) assists in maintaining lateral sway balance during the rising motion.[22,23]

The results of the current study indicate that all COP variables—including COP area, total COP path length, average COP velocity, and COP path length in the mediolateral direction—differed significantly between the double-leg STS and single-leg STS tests, which aligns with the study's hypothesis. This phenomenon can be attributed to the smaller BOS in the single-leg STS compared to the double-leg STS. The restricted BOS inherent to the single-leg STS limits the body's movement range in critical variables, which would otherwise be greater with the larger BOS provided by the double-leg STS. Consequently, if the COP shifts outside of the already limited BOS during the single-leg STS, it will likely result in losing balance control.[20] This highlights the increased challenge of maintaining postural stability during single-leg tasks. This factor becomes particularly significant in populations with impaired balance, such as older adults or individuals recovering from lower limb injuries.[14,24,25]

The COP velocity indicates the speed at which the body's center of mass moves, serving as a crucial indicator of balance control. Effective regulation of movement speed is associated with reduced postural sway.[22] In the current study, participants exhibited lower COP velocity during the single-leg STS test, with speeds approximately half of those observed in the double-leg STS test. This reduction in velocity suggests a more controlled and deliberate movement pattern in the single-leg STS, likely due to the increased demand for balance imposed by the smaller BOS. However, when comparing the COP outcomes of the dominant and non-dominant legs, no significant differences were found across all COP values during the STS test. This lack of difference may stem from the comparable strength of the primary muscles involved in the movement, which allowed for similar movement speeds in the single-leg STS. Specifically, the hip abductor muscles, which play a critical role in maintaining balance in the frontal plane, enabled participants to sustain similar levels of stability during the single-leg STS task, regardless of which leg was tested.[20] This finding is further supported by the anteroposterior COP path length, which also showed no significant differences across all conditions between the single-leg and double-leg STS and between the dominant and non-dominant limbs.

The findings from the current study provide preliminary data for the single- and double-leg single-time STS task in healthy adults, which may serve as a basis for future research involving more prominent and more diverse populations. Additionally, the significant differences observed in movement time and COP variables between single-leg and double-leg STS tests suggest potential applications for balance assessment and functional mobility evaluation. Meanwhile, single-leg STS, which involves a small BOS and likely greater demands on muscle power and postural control, may hold promise as a tool for identifying balance impairments and functional deficits. Further research is needed to confirm its sensitivity and utility in clinical populations.

Several limitations should be acknowledged in the current study. First, although the quadriceps and hip abductors are primary muscles for the STS task, other core muscle strength may also impact STS performance. Notably, our study found no significant strength differences between the dominant and non-dominant limbs, which may limit the ability to evaluate the effects of asymmetries on STS performance. Therefore, future studies should consider assessing the role of additional postural muscles and further include participants with known strength asymmetries to explore their influence on postural control during this movement. Additionally, incorporating electromyographic (EMG) assessments could provide valuable information on muscle activation patterns, allowing for a more comprehensive understanding of the coordination and timing of muscle contractions during the STS task. Third, incorporating kinematic data analysis could expand outcome variables by offering detailed insights into joint movement and velocity while also providing a more nuanced understanding of the sub-phases within the STS movement. This approach would facilitate a deeper analysis of the biomechanical and temporal characteristics involved in the STS movement. Lastly, the study limited participants to those aged 18-25 with a normal BMI. This restriction may affect the generalizability of the findings to other populations. Future studies should include individuals with higher BMIs, middle-aged adults, and older adults to understand better how single-leg tasks are performed across a broader range of clinical and demographic groups. Exploring these populations could yield valuable insights for clinicians, particularly in assessing balance and functional mobility in individuals with varying physical capabilities and health conditions.

## Conclusion

This study compared movement time and COP outcomes during single-leg (dominant and non-dominant legs) and double-leg STS tests in healthy participants. The results indicated that the single-leg STS (both limbs) exhibited significantly longer movement time but lower COP sway than the double-leg STS, except for COP path length in the anteroposterior direction. However, no significant differences were found between the dominant and non-dominant legs in any outcome during the single-leg STS. These findings provide preliminary reference values for STS tasks in healthy adults and may serve as a potentially helpful tool for assessing balance impairments and functional mobility. Further research is required to validate its sensitivity in pathological populations.

## Conflict of interest

The authors declare no conflict of interest.

## Ethical approval

The study was approved by the ethical committee of the Institutional Review Board. All participants of this study gave their written informed consent to participate.

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