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Biomechanical differences between sit-to-stand performances using one leg and two legs in young adults

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ABSTRACT

Background: Sit-to-stand (STS) test is widely used as a functional test for the assessment of lower extremity function in the elderly. Performing the STS movement with one-leg was introduced as an assessment of lower extremity muscle strength in young adults; however, the biomechanical differences between the traditional two-leg STS movement and one-leg STS movement have not been reported. The purposes of this study were to characterize and compare the kinematic and kinetic differences between the one-leg and two-leg STS movements.

Materials and methods: Fifteen young adults (8 men and 7 women) with mean age 26.18±3.88 years participated in this study. The kinematic and kinetic data during one-leg and two-leg STS testing conditions were collected and analyzed using force plates and a three-dimensional motion analysis system.

Results: Performance time was significantly longer in the one-leg STS condition than the two-leg STS condition (p<0.001). The peak joint angular positions of the hip, knee, and ankle were not different between the two STS testing conditions. All kinetic variables of the one-leg STS condition were significantly higher than those of the two-leg STS condition (p<0.05), except peak knee joint power in the concentric phase.

Conclusion: The more demanding task of the one-leg STS condition led to several changes in the joint moment and joint power of the lower extremity. The hip extensor and ankle dorsiflexor muscles demonstrated significant roles in addition to the knee extensor muscles during the one-leg STS task.

Introduction

Sit-to-stand (STS) test is often used as a functional test of lower extremity (LE) muscle strength.[1-4] The traditional form of STS test uses both legs to perform the STS task. Performance time of STS tests was reported to have a significant correlation with strength of major lower limb muscles in healthy older community-living adults.[1,2] Due to relatively high LE muscle strength of young adults compared to older adults[5], several tests that require greater demand of the LE muscles have been proposed as a functional test for assessment of LE strength in young adults. A one-leg-rising test was formerly used to assess leg extensor muscle function in patients with hip and knee arthritis[6] and later was modified as a LE functional performance test in young soccer players.[7]

Recently, an alternate form of STS test was introduced to assess LE muscle strength in young adults called "one-leg STS test".[8] A one-leg STS test is defined as a test to measure the ability to perform repeated sitting to standing movement using one leg. Concurrent validity of a one-leg STS test was reported with significant moderate relationships between the strength of LE muscles and performance time of a five-repetition one-leg-STS test. The advantages of a one-leg STS test include ease of administration and suitability in

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clinical settings. Performance of STS results in mechanical changes from a stable position to a less stable position with a higher body's center of mass position and a smaller base of support. Therefore, it is a challenging movement with great biomechanical demands, requiring joint torque as well as precise control of the body's center of mass within the base of support to complete the task.[9,10]

Biomechanical analyses of traditional two-leg STS movement have been extensively reported.[11-13] On the other hand, there is a paucity of research examining the biomechanical measures of a one-leg STS task. With greater demand placed on the LE muscles, individuals may exhibit different motion strategy and distributions of the hip, knee, and ankle joint moments when performing the sit-to-stand task with only one leg. Comparison of the mechanical differences between performance of the one-leg STS and the traditional two-leg STS tests is needed in order to provide basic information of this alternate form of STS test. Findings of the present study may aid the therapists for appropriate selection of the type of STS test for their clients in different age groups. Therefore, this present study aimed to investigate the kinematic and kinetic variables of a one-leg STS movement in healthy young adults and compare with those of the two-leg STS movement

Materials and methods

Fifteen young, healthy adults (8 men and 7 women; mean age 26.18±3.88 years; mean mass 55.05±11.09 kg; mean height 1.65±0.97 m.) participated in the study. The sample size was calculated by the G*Power 3.1.7 program for t-tests: Mean difference between two dependent means (matched pairs). To achieve 80% statistical power, effect size of 0.7 (based on a previous study comparing trunk kinematics between the one-leg and two-leg STS movements[14]) with an alpha level of 0.05, fifteen participants were required. Participants were included in the study if they were between the age of 20 and 40 years and excluded if they had neurological or musculoskeletal disorders that would affect the ability to perform STS movements. The study protocol was approved by the institutional review board of Mahidol University (MUICRB, COA no. 2016/180.2810). All participants gave written informed consent before the data collection process.

Kinematic and kinetic data were collected using the Vicon™ Motion Analysis System (Vicon™ Motion Systems Ltd, Oxford, UK), consisting of ten cameras with a sampling frequency of 100 Hz, integrated with two force platforms (AMTI OR6-7 Series 4000, Advanced Mechanical Technologies Inc., Boston, USA) with a sampling frequency of 1000 Hz. Thirty-four reflective markers were placed on the participant's body according to the Plug-In Gait-Full Body standards available within the Vicon Motion system. The 3-D motion and force data from the selected trials were processed using Vicon Nexus software (version 3.5.1) and were filtered with a 4^{th}-order Butterworth zero-lag filter, with a cut-off frequency of 8 and 20 Hz, respectively. The kinematic and kinetic variables were calculated using the Vicon Plug-in Gait Model.[15]

Each participant performed both one-leg and two-leg STS testing conditions (Figure 1). A sit-to-stand test with five repetitions was used in order to compare to a common form of standard two-leg STS test[2] (a five-repetition chair stand test). Half of the participants performed the one-leg STS testing condition first while the other half performed the two-leg STS testing condition first. An armless, height-adjustable chair was used in the testing. All trials were performed with bare feet. Participants began each trial in a seated position with their arms folded across their chests and their feet shoulder-width apart and placed slightly behind the knee joint. The seat height was adjusted to the knee joint level such that the knee of the tested leg was set at 100 degree flexion. The verbal instructions were "Please stand up and sit down five times as quickly and safely as possible. Stand up until your legs are fully straightened and your buttocks are against the seat when you sit down, Ready and Start." Timing began on the command of the examiner and stopped when the participant's buttocks touched the seat after the fifth stand. Before beginning actual data collection, participants performed two practice trials to familiarize themselves with the test while the examiners made sure the motion capture and force plates functioned properly. Each participant performed two trials in each condition and the fastest of the two trials was used for data analysis. A three-minute rest was allowed between trials to avoid fatigue. Testing procedures of the one-leg STS testing condition were similar to the two-leg STS testing condition except using only the dominant leg to perform the STS task. The non-test leg (non-dominant side) was lifted just above the floor throughout the test and not allowed to assist the STS movement. The dominant leg was determined by leg dominant test.[16] Twelve participants out of 15 had right-leg dominance. Trials were discarded if the participant's non-tested foot touched the floor during the trial.

Figure 1 *Illustration of the sit-to-stand testing conditions a) one-leg sit-to-stand condition b) two-leg sit-to-stand condition.*

Kinematic variables included the peak joint angular position of the hip, knee, and ankle. The kinetic variables included the peak vertical ground reaction force (VGRF), peak joint moment and joint power of the hip, knee and ankle. Since the nature of the STS movement mainly occurs in the sagittal plane, only a sagittal plane evaluation of the variables was of interest in this study. VGRF data and the hip angular position were used to identify the event and phase of the STS test. Each of the sit-to-stand task comprised of five repetitions (Figure 2). The data from the second to fourth repetitions were used for data analysis. Each repetition was divided into the sit-to-stand part (concentric phase) and stand-to-sit part (eccentric phase). Vertical lines in Figure 2 were added to demonstrate the separation of the two parts. The joint angular positions and kinetic variables of each repetition were time-normalized to create ensemble-averaged across participants to assist visual inspection. The mean difference of the kinematic and kinetic variables between STS test conditions was calculated by subtracting the value of the two-leg STS test from that of the one-leg STS test. The percent mean difference is the proportion of the mean difference divided by the average of the two values.

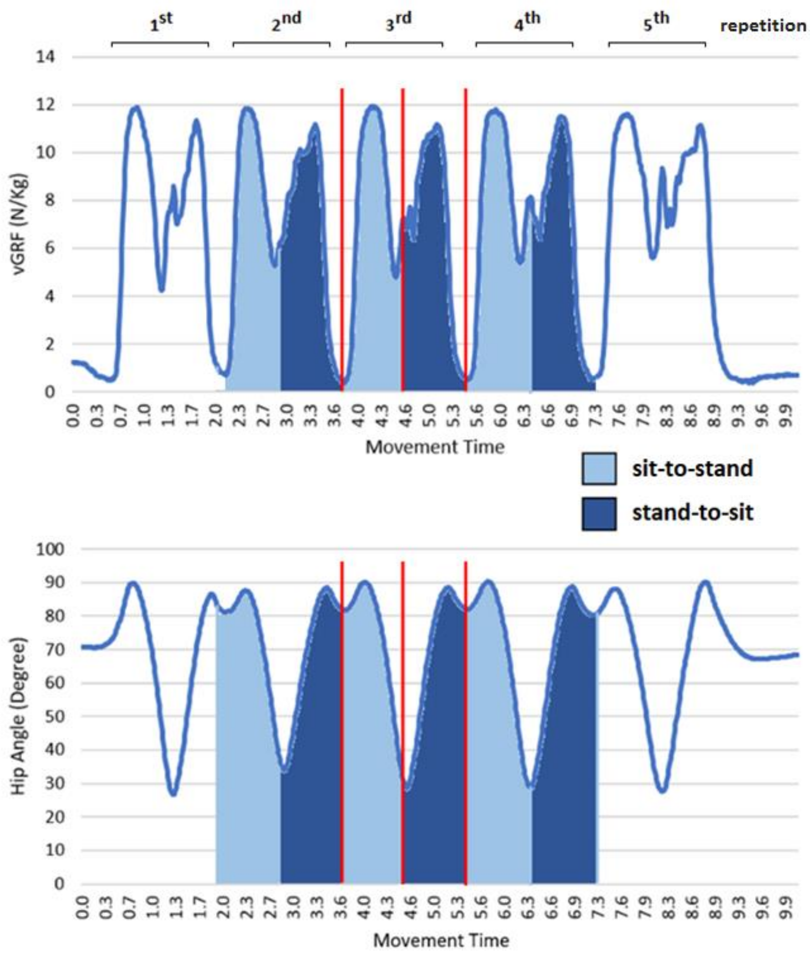

Figure 2. *Typical VGRF and hip joint angle profiles of a sit-to-stand test.*

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics (version 23) for Windows. The Kolmogorov-Smirnov test was used to assess the normal distribution of the data. Paired t-test was used to compare the differences in the joint angular displacement and kinetic variables between the one-leg and two-leg STS tests. Statistical significance level was set as $p<0.05$ for all analyses.

Results

Mean performance time of the one-leg STS condition was significantly longer than that of the two-leg STS condition ($p<0.001$). The mean joint angular positions of the hip, knee, and ankle were not different between the two STS testing conditions. The means and SDs of the performance time and peak joint angular positions of both STS conditions are summarized in Table 1.

Table 1 Comparison of the performance time and joint angular position between the one-leg and two-leg STS testing conditions

Variables	One-leg STS	Two-leg STS	Mean difference	% Mean difference	*p* value
Performance time (s)	11.63±2.96	8.27±1.42	3.36	33.77	<0.001**
Peak joint angular position (deg)					
Max hip angle	81.99±8.43	83.62±6.85	-1.63	-1.97	0.514
Min hip angle	8.22±9.14	6.67±8.65	1.55	20.82	0.142
Max knee angle	86.35±5.67	87.12±4.79	-0.77	-0.88	0.445
Min knee angle	7.14±9.12	6.42±6.12	0.72	10.62	0.216
Max ankle angle	21.91±5.79	20.33±3.42	1.58	7.48	0.416
Min ankle angle	3.19±4.16	2.90±3.75	0.29	9.52	0.614

Note: *** significantly different at p<0.01*

VGRF, joint moment and joint power of the one-leg and two-leg STS tests were generally similar in profile pattern but different in magnitude. Illustrations of the ensemble -averaged data of the VGRF, joint moments, and joint powers are shown in Figures 3, 4 and 5, respectively. VGRF profile contains two separated peaks. The first peak occurs in the sit-to-stand portion (concentric phase) and the second peak occurs in the stand-to-sit portion (eccentric phase). The values of the peak VGRF, peak joint moment and peak joint power are shown in Table 2. All kinetic variables of the one-leg STS condition were significantly higher than those of the two-leg STS condition ($p<0.05$), except peak knee joint power in the concentric phase.

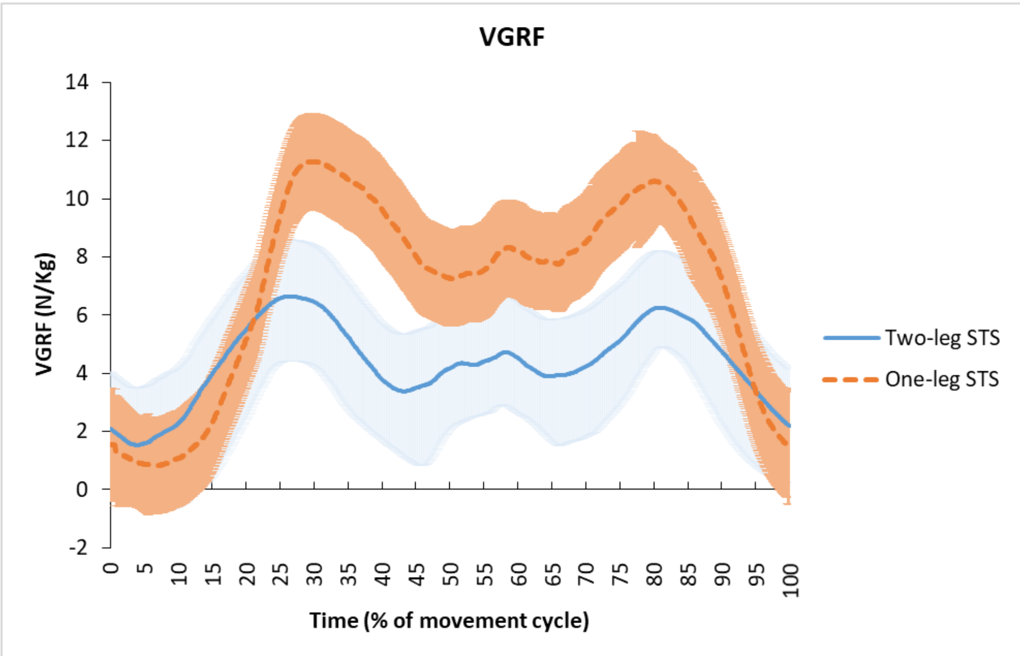

Figure 3. *Ensemble-averaged data of the vertical ground reaction force (VGRF).*

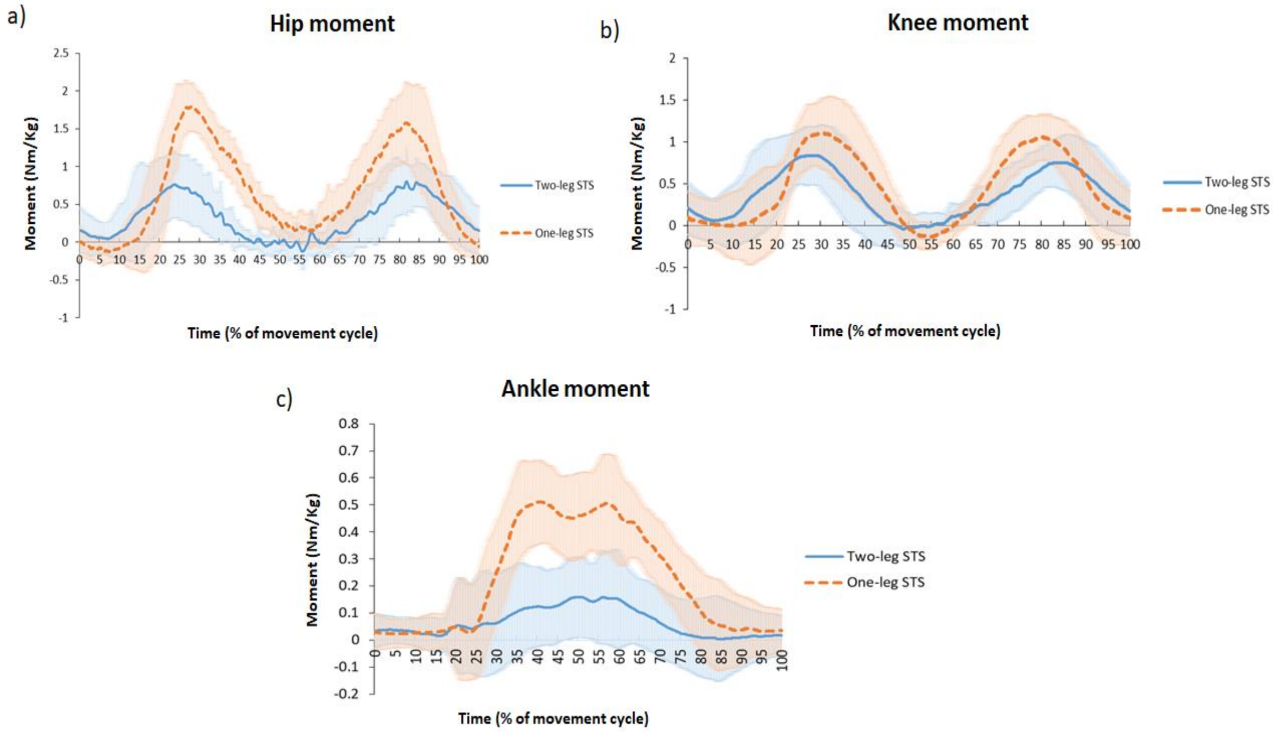

Figure 4. *Ensemble-averaged data of a) hip joint moment, b) knee joint moment and c) ankle joint moment.*

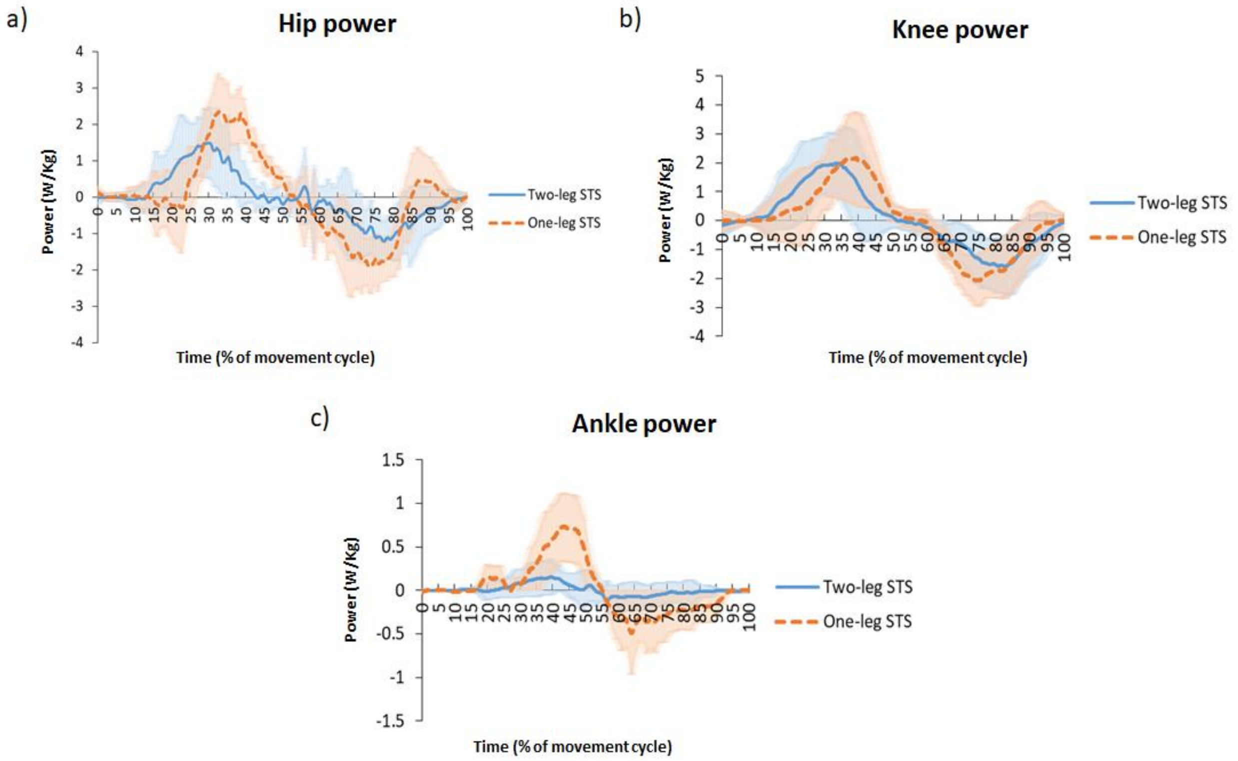

Figure 5. *Ensemble-averaged data of a) hip joint power, b) knee joint power c) ankle joint power.*

Table 2 Comparison of the kinetic variables between the one-leg and two-leg STS testing conditions.

Kinetic variables	One-leg STS	Two-leg STS	Mean difference	% Mean difference	*p* value
Peak VGRF (N/kg)					
Concentric phase	11.61±1.07	7.38±0.92	4.23	44.55	<0.001**
Eccentric phase	11.32±1.05	6.70±0.94	4.62	51.28	<0.001**
Peak joint moment (Nm/kg)					
Hip - concentric phase	2.03±0.26	1.02±0.33	1.01	66.23	<0.001**
Hip - eccentric phase	1.92±0.40	1.00±0.39	0.92	63.01	<0.001**
Knee - concentric phase	1.35±0.30	1.13±0.24	0.22	17.74	<0.001**
Knee - eccentric phase	1.27±0.28	0.92±0.21	0.35	31.96	<0.001**
Ankle - concentric phase	0.73±0.21	0.15±0.07	0.58	131.82	<0.001**
Ankle - eccentric phase	0.71±0.16	0.22±0.10	0.49	105.38	<0.001**
Peak joint power (Watt/kg)					
Hip - concentric phase	3.22±0.72	2.25±0.99	0.97	35.47	0.003**
Hip - eccentric phase	3.00±0.78	2.17±0.83	0.83	32.11	<0.001**
Knee - concentric phase	3.01±0.91	2.90±1.10	0.11	3.72	0.625
Knee - eccentric phase	2.42±0.70	2.12±0.72	0.30	13.22	0.024*
Ankle - concentric phase	0.57±0.14	0.24±0.15	0.33	81.48	<0.001**
Ankle - eccentric phase	0.58±0.44	0.21±0.11	0.37	93.67	0.002**

***Note**: * significantly different at p < 0.05, ** significantly different at p<0.01*

Discussion

The results revealed that several biomechanical differences exist between the two STS testing conditions. Participant's body weight is considered an external load that the leg muscles have to overcome during standing up and sitting down. For a usual STS task using two legs, the external load is opposed by muscles of both legs, whereas in the one-leg condition, this same external load is placed solely on one leg which induced a strategy change in STS performance. It took 3.36 seconds longer for the participants to complete the one-leg STS condition compared with the two-leg STS condition. The results are in accordance with Savelberg el al[17] who examined the effect of load added to the body while performing a traditional two-leg sit-to-stand task. Increased extra load from 30% to 45% of body weight resulted in increased movement time, increased maximum joint moments at hip, knee and ankle joints and changes in muscle activation patterns of major leg muscles. In this study, the kinematic variables (joint angular positions) were not different between the two testing conditions. The LE joint position of the tested leg at the starting position was the same for both STS testing conditions. For each repetition of the STS tests, the participants returned to sit at the same seat height and stood up to full upright position. Therefore, the ranges of motion of the hip, knee, and ankle joints were not different between STS conditions.

Almost all kinetic variables were found to be different between the two STS testing conditions. Increased VGRF indicated larger net muscle force is generated by the acting leg muscles during the one-leg STS condition.[18] VGRF of the one-leg STS condition increased by 4.23 N/kg (44.55%) and 4.62 N/kg (51.28%) in the concentric and eccentric phases, respectively. Our results are supported by previous studies investigating the effect of increasing load on ground reaction force during squatting which is a similar movement to STS mainly using the LE muscles. Kellis el al[19] examined the effect of increasing load on the ground reaction force during barbell squat and found that GRF increased significantly as external load increased. Dali et al[20] found that deep squatting generated the highest VGRF compared to semi and half squatting.

It is clear that major leg muscles were more activated to control the whole body up and down repeatedly throughout the one-leg STS condition. Previous studies reported that the knee and hip extensors play a major role in the sit-to-stand movement.[21-23] In this study, although all the hip, knee, and ankle extensor moments and joint power significantly increased during the one-leg STS condition, it is interesting that the largest increase in joint moment and power occurred at the ankle joint. The mean increases of the ankle joint moment were over 131 and 105 percent in the concentric and eccentric phases, respectively, indicating the crucial role of the ankle muscles in stabilizing the foot and lower leg in order to achieve sufficient balance during this demanding task[24].

For the two-leg STS condition, the largest joint moment was originated from the knee joint. However, the higher moment about the knee during the two-leg STS condition is shifted to proportionally higher moments about the hip and ankle during the one-leg STS condition. This could be due to the more demanding task of the one-leg STS condition which causes this change in the net moment. The hip extensor muscles which have larger muscle size were recruited more to produce sufficiently net joint moment to perform the task. The peak hip extensor moment increased over 60 percent revealing the synergistic role of the hip extensor muscles during the one-leg STS condition. Savelberg et al[17] explained that the primary adaptation in response to added load is decreasing in movement time and increasing in knee extension moment. If the maximum capacity of the knee extensor strength is sufficient, individuals can perform the task without inducing a strategy change. Secondly, if a strategy change has been induced, the hip extension torque is more required. The latter explanation is in line with our results which found that the hip extensor muscles moment increased with the one-leg STS condition indicating that the hip strategy is preferred as the one-leg STS task required greater control of dynamic balance.

The results of the study indicated that compared to the traditional two-leg STS test, the one-leg STS test is a challenging task which is suitable for assessment of LE muscle function in young adults as it demands greater amount of force production from the LE extremity muscles to complete the STS task. However, this present study had some limitations. First, we investigated only the one-leg STS movement performed by the dominant leg. It might be possible that person may perform differently on their non-diminant side. However, Steingrebe el at[25] reported no significant differences in knee joint loading between the dominant and the non-dominant side during a unilateral sit-to-stand movement. Second, direct measurement of the LE muscle strength was not done in this study. Therefore, we cannot directly explained how much of the maximum strength capacity of the LE muscles would be required for the one-leg STS movement compared to the typical two-leg STS movement. All the limitation issues should be further investigated in future study.

Conclusion

Compared to a typical two-leg sit-to-stand movement, there was an increase in performance time of a one-leg sit-to-stand test. The patterns of angular displacements of the hip, knee and ankle joints of the two STS sit-to-stand movements were generally similar. In addition, the more demanding task of the one-leg STS condition led to several changes in the joint moment and joint power of the lower extremity. The hip extensor and ankle dorsiflexor muscles demonstrated significant roles in addition to the knee extensor muscles during the one-leg STS task.

Conflicts of interests

The authors declare no conflicts of interests.

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