
Objective: To investigate the effects of different foot positions during the sit-to-stand (STS) movements with stroke subjects.

Design: Cross-sectional.

Setting: Research laboratory.

Participants: Twelve chronic stroke subjects (N=12).

Interventions: Not applicable.

Main Outcome Measures: Differential latency and electromyography (EMG) activity of the tibialis anterior, soleus, quadriceps, and hamstring muscles of the affected leg as well as the movement time, time of seat-off, weight symmetry, and rising index were obtained while the subjects performed the STS movements by using 4 different strategies: spontaneous; symmetric; asymmetric-1, with the affected foot behind; and asymmetric-2, with the unaffected foot behind.

Results: Compared with the spontaneous strategy, the soleus showed the greatest differential latency in the asymmetric-2 strategy, the hamstrings had lower EMG activity in the symmetric strategy, and the movement time was greater in the asymmetric strategies.

Conclusions: The asymmetric 2 strategy appeared to be the least favorable, whereas the spontaneous and the symmetric strategies appeared to be more favorable in improving the STS performance. Based on these findings, allowing the subjects to adopt the spontaneous strategy or training of the symmetric strategy could result in greater benefits for subjects with higher chronicity and higher functional levels, such as those evaluated in the present study.

Key Words: Electromyography; Hemiparesis; Rehabilitation; Stroke.

© 2009 by the American Congress of Rehabilitation Medicine

S TROKE IS DEFINED AS A neurologic deficit in the brain after vascular injuries.1 Muscular weaknesses contralateral to the injury side are the most common problems of subjects who have suffered a stroke and may lead to difficulties in performing activities of daily living, such as rising from a chair without assistance.2,3

The STS movement is one of the most common functional activities, and it is essential for the maintenance of an individual’s independence.4-6 During the period of recovery from a stroke, the loading on the affected leg tends to be spontaneously avoided, leading to difficulties in accomplishing the STS tasks.7-12 If the affected side is neglected during functional activities, this will become a habit and will stimulate disuse, leading to the development of the learned nonuse phenomenon.13,14

The incapacity to bear weight on the affected leg can occur because of pain, spasticity, balance deficits, sensorial problems, neglect, muscular weaknesses, and changes in postural control.14,15 Thus, subjects with hemiparesis after a stroke may develop compensatory mechanisms that can affect the components related to dynamic balance and muscular activation patterns to perform the STS movement.

The STS task is often stimulated and trained earlier during rehabilitation programs.16,17 The practice of this movement, through strategies that promote the weight bearing on the affected leg, can provide benefits for the return of more functional movements and prevention of falls and the learned nonuse of the limb.8,14,16

The learned nonuse of the limb can be reversed by the forced use of the affected leg.8 In accordance with Engardt and Olsson,10 subjects with hemiparesis, during the acute phase, when requested, are able to load more weight on the affected leg. Some strategies can be used to favor the load on the affected leg during the STS movements. The change in position of the affected leg backwards, for example, is a common strategy used for training in clinical practice; however, its effects in subjects with chronic hemiparesis are still not well documented. Therefore, the aim of the present study was to investigate the effects of different positions of the lower limbs during the STS movement with chronic stroke subjects by using 4 distinct strategies on the temporal and EMG measurements.

METHODS

Subjects

Community-dwelling stroke subjects participated in the study according to the following inclusion criteria: having had only 1 episode of stroke, having had the stroke at least 6 months before the study to ensure chronicity,18 being over 60 years of age, having weakness and/or spasticity on the affected leg during the acute phase, when requested, are able to load more weight on the affected leg. Some strategies can be used to favor the load on the affected leg during the STS movements. The change in position of the affected leg backwards, for example, is a common strategy used for training in clinical practice; however, its effects in subjects with chronic hemiparesis are still not well documented. Therefore, the aim of the present study was to investigate the effects of different positions of the lower limbs during the STS movement with chronic stroke subjects by using 4 distinct strategies on the temporal and EMG measurements.

List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>QUAD</td>
<td>Quadriceps</td>
</tr>
<tr>
<td>ROM</td>
<td>Range of motion</td>
</tr>
<tr>
<td>SOL</td>
<td>Soleus</td>
</tr>
<tr>
<td>STS</td>
<td>Sit to stand</td>
</tr>
<tr>
<td>TA</td>
<td>Tibialis anterior</td>
</tr>
</tbody>
</table>
side, being able to rise from a chair without aid of their hands, and showing no receptive aphasia. Subjects were excluded if they had any musculoskeletal problems or any other neurologic disease as well as any auditory or visual deficits that could prevent data collection.

Outcome Measures

Measures of EMG activity (latencies and quantity), time to perform the STS (movement time), time of the seat-off, rising index, and weight symmetry were obtained while the subjects performed the STS in spontaneous, symmetric, and asymmetric conditions. These measures were selected because they were used to evaluate the STS tasks with healthy subjects and subjects with chronic disabilities.7,10,19,20

Instrumentation

The EMG activities of the TA, SOL, QUAD, and hamstring muscles during the STS movements were assessed with an EMG apparatus (MP150WSWa). This device had 2 amplifiers connected to a computer, which had an input impedance of 2 MΩ and CMRR of 1000 MΩ and allowed data acquisition at frequencies from 10 to 1000Hz. Data were collected at a frequency of 1000Hz. Surface, active, bipolar, TSD 150 electrodes* with diameters of 13.5, and impedance of 100 MΩ were used for data collection.

The triaxial accelerometer* was used to determine the movement time to perform the STS and was placed on the participants’ forehead,19 which described the vertical (Z), horizontal (Y), and lateral (X) acceleration. Its 3 channels were connected to the electromyography interface, and only the information of the horizontal and vertical axes, in the sagittal plane, were considered for analyses. The time when the seat-off occurred was obtained with 2 force sensors whose signals ranged between −1V to +1V and were placed on the laboratory stool surface used for the tests. The time of the seat-off was determined by the baseline changes in the voltage signals.

The Balance Master System version 8.3* was used to evaluate the rising index and the left/right weight symmetries. The rising index registered the percentage of body weight exerted by the lower limbs during the rising phase. The affected/nonaffected weight symmetry indicated the amount of weight born by each leg during the rising phase for 5 subsequent seconds.20 The accelerometer, force sensors, and Balance Master System were all connected through an interface of the Biopac System for synchronization with electromyography, which allowed all of the records to be simultaneously collected.

Procedures

Before the initiation of data collection, subjects were informed about the objectives of the study and invited to sign a consent form, which was previously approved by the University Ethical Review Board. After this, demographic and anthropometric data were collected on all subjects to document their age and other clinically relevant information. In addition, for characterization purposes, data were obtained regarding the ROM for ankle dorsiflexion, self-paced walking velocity, muscle tone, and isokinetic torque measures of the flexor and extensor muscles of the hip, knee, and ankle bilaterally at a speed of 60° a second. The measures of peak torque were described as the ratios between the affected and nonaffected sides.

After skin preparation, which included shaving, rubbing, and cleansing with alcohol, the participants were instructed to assume a standing position on the Balance Master System platform. Surface electrodes were placed in pairs and parallel to the muscle fibers following previously described procedures.19,21 For the TA, the electrodes were placed on the anterior, lateral, and superior aspects of the tibia at approximately one third of the distance between the knee and the ankle; for the SOL, on the inferior and lateral aspects of the leg, below the belly of the gastrocnemius; for the QUAD, at middistance between the anterior-superior iliac spine and the superior patellar edge; and for the hamstrings, medially at the middistance point between the gluteal fold and knee joint. The reference electrode was placed over the patella of the unaffected leg. The participants were then seated on a backless wooden stool, which was adjusted to 100% of the height of the subjects’ knees determined by the distance from the lateral knee joint line to the floor, but the amount of thigh loading was not monitored.

Four strategies were investigated during the STS movements: spontaneous, without instructions on the initial foot position; symmetric, with both ankles placed backwards at the same level with a dorsiflexion angle of the unaffected leg ranging between 10° and 15°; asymmetric-1, with the affected leg placed behind the unaffected leg; and asymmetric-2, with the unaffected leg placed behind the affected leg.

To guarantee adequate positioning of the lower limbs for the symmetric and asymmetric strategies, subjects were requested to sit on a wooden stool and to move the unaffected ankle backwards as much as possible to measure the angle of the ankle with a universal goniometer. From this measure, which ranged between 10° and 15°, a mark aligned with the calcaneus was placed on the floor to position the lower limbs backwards. With a measuring tape, the anterior distance, equivalent to half of the length of the foot, was obtained from the previous line and was also marked from the anterior position of the calcaneus, which was used during the performance of the asymmetric strategies.

The STS task was performed with the subjects’ feet supported on the Balance Master System platform and their arms across the chest to prevent the use of the upper limbs during the execution of the task. The participants were instructed not to move their feet and to stand as fast as possible from the initial instructions of the Balance Master System. When the standing position was attained, they were asked to maintain this position for 5 seconds. After familiarization, 3 trials were obtained for each strategy, and the mean values were considered for analyses. Before each trial, the positioning of the feet was ensured, and a brief rest interval was allowed between trials. The strategies were randomly assigned, except for the spontaneous strategy, which was always performed first.

Data Reduction and Analysis

EMG data processing was performed by using the Acknowledge software. The EMG signals were full wave rectified and low-pass and high-pass filtered with cutoff frequencies of 500 and 10Hz, respectively. The muscular latencies were determined by the time between the visual Balance Master System signal and the EMG onset for each muscle. The onset of muscular activity was considered when the values exceeded 2 SDs from the mean values observed at baseline for a 50-ms duration.22

To compare the muscular latency between the conditions, a value of 0 was considered for the time instance of the seat-off of each trial, and the differential latencies were calculated between the EMG onset for each muscle and the time instance of the seat-off. In this manner, muscles that initiated their activities before the seat-off showed negative latencies. The quantification of EMG activity was expressed by root mean squares,24 which were normalized by the maximum signal amplitude and described in percentages23 during intervals of
0.8s, which were between 0.4s before and 0.4s after the time of the seat-off. The seat-off is considered to be the time of the highest muscular activation during the STS.6,8 and, therefore, has been recommended for quantifying EMG.18,22

The beginning of the movements was detected from the initial changes of the y and z axes of the accelerometer and the end of the movements to the return to the baseline values. To determine the mean values at baseline, the mean values during 1 second were calculated before the Balance Master System signals with the subjects at rest. A threshold of the baseline was determined by adding 2 SDs to the mean values. The beginning or the end of the movements was determined as the time when the values were over or under the baseline for at least 0.1 seconds. Body weight was used to normalize the rising index based on the following formula: (rising index/body mass) × 100%. The weight-bearing symmetry values were expressed as the ratios between the affected and nonaffected sides, with the value of 1 as an indication of perfect symmetry.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range (minimum–maximum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>68.00±7.14</td>
<td>60–80</td>
</tr>
<tr>
<td>Time since onset of stroke (y)</td>
<td>7.67±3.99</td>
<td>1–14</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>66.73±11.07</td>
<td>53.50–86.90</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.62±0.09</td>
<td>1.51–1.76</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.36±2.89</td>
<td>21.72–30.43</td>
</tr>
<tr>
<td>Knee height (m)</td>
<td>0.47±0.03</td>
<td>0.43–0.53</td>
</tr>
<tr>
<td>Affected DF ankle ROM (degrees)</td>
<td>8.83±6.62</td>
<td>0–15</td>
</tr>
<tr>
<td>Nonaffected DF ankle ROM (degrees)</td>
<td>14.83±2.76</td>
<td>10–20</td>
</tr>
<tr>
<td>Self-paced walking velocity (m/s)</td>
<td>0.68±0.25</td>
<td>0.34–1.08</td>
</tr>
<tr>
<td>Muscle tone (Modified Ashworth scale)</td>
<td>NA</td>
<td>0–3</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; DF, dorsiflexion; NA, not applicable.

Results

Twelve stroke subjects, 6 men and 6 women with a mean age of 68.00±7.14 years, a BMI of 25.25±2.89 kg/m², and a mean time since onset of stroke of 7.67±3.99 years completed all tests (table 1). Seven subjects were classified as fast, 3 as medium, and 2 as slow gait speed in accordance with the criteria proposed by Olney et al.23 Some patients were not able to generate sufficient torque at the hip and ankle joints. Therefore, the isokinetic strength data related to the peak torque ratios of the affected and nonaffected legs were obtained for 12 subjects who completed the knee tests, 11 for the hip, and 6 for the ankle. The ratio values were 0.89 and 0.70, respectively, for the hip flexors and extensors, 0.56 and 0.68 for the knee flexors and extensors, and 0.81 and 0.56 for the ankle dorsiflexors and plantar flexors.

Table 1: Participants’ Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Spontaneous</th>
<th>Symmetric</th>
<th>Asymmetric 1</th>
<th>Asymmetric 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIFLAT TA (s)</td>
<td>–0.36±0.20</td>
<td>–0.27±0.21</td>
<td>–0.31±0.16</td>
<td>–0.26±0.20</td>
</tr>
<tr>
<td>DIFLAT SOL (s)</td>
<td>–0.15±0.15*</td>
<td>–0.10±0.08*</td>
<td>–0.10±0.12*</td>
<td>–0.03±0.13*</td>
</tr>
<tr>
<td>DIFLAT QUA (s)</td>
<td>–0.21±0.30</td>
<td>–0.31±0.20</td>
<td>–0.27±0.25</td>
<td>–0.34±0.22</td>
</tr>
<tr>
<td>DIFLAT HMS (s)</td>
<td>–0.27±0.13</td>
<td>–0.20±0.17</td>
<td>–0.18±0.09</td>
<td>–0.20±0.08</td>
</tr>
<tr>
<td>EMG TA (mV)</td>
<td>0.17±0.04</td>
<td>0.26±0.23</td>
<td>0.18±0.04</td>
<td>0.17±0.04</td>
</tr>
<tr>
<td>EMG SOL (mV)</td>
<td>0.09±0.03</td>
<td>0.10±0.03</td>
<td>0.09±0.04</td>
<td>0.08±0.04</td>
</tr>
<tr>
<td>EMG QUA (mV)</td>
<td>0.21±0.03</td>
<td>0.22±0.04</td>
<td>0.21±0.03</td>
<td>0.19±0.03</td>
</tr>
<tr>
<td>EMG HMS (mV)</td>
<td>0.16±0.04*</td>
<td>0.13±0.02*</td>
<td>0.15±0.03*</td>
<td>0.16±0.03*</td>
</tr>
<tr>
<td>MT (s)</td>
<td>1.93±0.29*</td>
<td>1.94±0.25*</td>
<td>2.16±0.34*</td>
<td>2.16±0.46*</td>
</tr>
<tr>
<td>SEAT-OFF (s)</td>
<td>0.91±0.13</td>
<td>0.90±0.13</td>
<td>0.89±0.12</td>
<td>0.92±0.13</td>
</tr>
<tr>
<td>RISING INDEX (%)</td>
<td>11.63±4.32</td>
<td>10.07±4.00</td>
<td>10.77±4.61</td>
<td>10.10±3.45</td>
</tr>
<tr>
<td>SYMMETRY (ratio)</td>
<td>0.59±0.30</td>
<td>0.64±0.35</td>
<td>0.74±0.73</td>
<td>0.47±0.30</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± SD.

Abbreviations: DIFLAT, differential latency; EMG, electromyographic activity (% peak of the maximum activity); HMS, hamstrings; MT, movement time; QUA, quadriceps; SOL, soleus; TA, tibialis anterior.

* Differ significantly (P < 0.05).

† Differ significantly (P < 0.01).

‡ Differ significantly (P < 0.001).

Arch Phys Med Rehabil Vol 90, February 2009
values. Finally, no significant differences were found between the strategies for the rising indices, although the greatest values were observed for the spontaneous strategy.

**DISCUSSION**

**Movement Time and Seat-Off**

The time to perform the STS is one of the main indicators of functional ability. Hemiparetic subjects require more time to perform this movement compared with healthy subjects, and Cheng et al. reported that a greater duration to perform this activity can be indicative of falls.

Subjects with hemiparesis were slower to perform the STS movements when they used the asymmetric strategies. Because no differences were found for the durations of the movements between the strategies until the time instance of the seat-off, it can be concluded that the increases of the total movement time occurred because of a prolongation of the postseat-off phase or its extension, which requires greater control and work to generate more force to raise the body. This indicates poorer performance of the hemiparetic subjects when performing the movements using these asymmetric strategies. Such strategies are not routinely used by these subjects and could have caused greater complexity of the movements, thus increasing their duration. On the other hand, the subjects were faster when they used the spontaneous and symmetric strategies, and these strategies appeared to have contributed to better performance during the accomplishment of the task.

**Symmetry and Rising Index**

In accordance with Cheng et al., the maintenance of postural symmetry during the STS movement may improve the performance of this task and also reduce the incidence of falls in subjects with hemiparesis. Although gains in postural symmetry are one of the main goals of the rehabilitation programs with these subjects, evidence that symmetry exerts an important role for functional performance is lacking. Teixeira-Salmela et al. did not find differences in weight symmetry measures of hemiparetic subjects during STS movements after a program of muscle strengthening and physical conditioning. This suggested that this postural asymmetry was a typical feature of hemiparetic subjects and seemed not to affect the functional performance of chronic stroke subjects.

Similarly, the subjects in this study did not show differences in the weight symmetry values, independent of the used strategies. Thus, to maintain weight-bearing symmetry while performing the STS movements might not be relevant for the functional performance of this task by these subjects. In the present study, the spontaneous strategy was shown to be more favorable for the subjects with hemiparesis to perform the STS movements because the rising index was maximal during this strategy.

**EMG Parameters During the STS Movement**

In accordance with Cheng, the TA, SOL, QUAD, and hamstring muscles played essential roles in the anterior-posterior stabilization of the ankle and knee joints during the STS tasks with healthy subjects. The activity of these muscles was compromised regarding the activation intensity and the onset latency in subjects with hemiparesis.

In the present study, the beginning of the SOL muscle activation was delayed when the unaffected foot was placed behind, in comparison to the spontaneous strategy. However, the differential latencies of the SOL muscle showed that this muscle was activated before the seat-off during all investigated strategies. It is well documented that, in healthy subjects, the SOL is the last muscle to be activated and its activation occurs after the seat-off during the performance of the STS movements. In healthy subjects, the function of the SOL is related to the deceleration and stabilization at the end of the movement once in the standing position. The fact that the subjects with hemiparesis activated the SOL earlier, independent of the lower-limb positions, suggests that there are possible changes of the motor control mechanisms of the ankle inherent to these subjects. These findings may be justified by the presence of the spasticity and weaknesses of this muscle, which have been shown to be the most affected of all investigated muscles.
No differences in the differential latencies of the TA, QUAD, and hamstring muscles were found between the strategies, and these muscles were also activated before the initiation of the seat-off and the same behaviors were observed with healthy subjects. In the latter situation, however, the changes of the initial lower-limb positions during the STS movements changed the TA latency because this muscle was considered to be responsible for the necessary preparatory postural adjustments. The absence of changes in the TA latencies observed in the subjects in the present study suggests that they showed a lack of adaptation of the preparatory postural adjustments to the various demands for the same task. This reinforced the previously cited hypotheses of the modified motor control at the ankle level.

The amount of muscular activity showed that hamstring was less activated in the symmetric strategy. In agreement with Lee et al., subjects with hemiparesis showed greater amounts of activation of this muscle during the last stage of STS to stabilize the knee in the standing position. The present results indicated that the positioning of the lower limbs backwards have decreased the necessity of the stabilization of these joints. This idea was reinforced by the results of Schultz et al who suggested that the backward positioning of the feet can improve the anterior-posterior stability and lead to a safer accomplishment of the STS movements.

Contrary to the present results, Brunt et al. found higher activation of the TA and QUAD muscles when the affected foot was positioned behind the nonaffected one. This positioning is often used in clinical practice for reducing the learned nonuse of the limb, although it has not been very well studied. Because the QUAD was considered one of the main generating muscles of the STS movement and the TA is considered to be essential for ankle stabilization, it would be expected that the use of such a strategy would increase the weight bearing on the affected leg, leading to increases in motor unit recruitment and more activation of the paretic muscles. This would lead to better performance of STS movements. However, differences between the study of Brunt et al. and the present study should be considered because they evaluated a sample of chronic stroke subjects with a mean time after stroke of 3.6 years, which was less than the 7.7 years observed in the present study. It is possible that because of the fact that the present subjects were more chronic, they could have been better adapted to spontaneously perform the STS movements by using different motor-control strategies as functional compensations. Other differences could also have been related to the methods used for the backward positioning of the affected leg. Brunt et al. used 100° of flexion of the affected knee, whereas, in this study, the ankle was the reference joint that showed the variability in ROM of the affected leg (0°–15°) because of the difficulty to make heel contact of the affected leg with the ground. This also may explain the differences between the studies for the asymmetric strategy with the affected foot positioned behind the nonaffected one. Therefore, the present findings do not support the use of this strategy for subjects with the characteristics of the present study.

Study Limitations

The EMG parameters investigated in the present study failed to find relevant differences between the strategies of lower-limb positioning. Other studies already pointed out the great variability in muscular latencies during the accomplishment of the STS movements in subjects with hemiparesis, and this variability was also observed in the present study. Moreover, these subjects were also instructed to perform the movement as fast as possible following the Balance Master System instructions. On the other hand, other studies used the natural speed for the accomplishment of the task and the speed of the movements, which could interfere with both the EMG variables and the movement patterns.

Another factor that needs to be discussed refers to the specific characteristics of the subjects in the present study. Although they were chronic, most of them were classified as fast in relation to the gait speed. This classification, proposed by Olney et al., suggests that the majority of these subjects could be considered minimally affected. Within this context, it is possible that the spontaneous and symmetric strategies were more natural and well known, and favored their performance of the STS movement.

CONCLUSIONS

The asymmetric strategy with the unaffected foot placed behind appeared to be less favorable for the accomplishment of the STS movements because it increased the movement time and delayed the activation of the soleus muscle. The asymmetric strategy with the affected foot placed behind did not show advantages for the studied subjects. The symmetric strategy revealed little need of stabilization of the affected knee, and the movement time was similar to that of the spontaneous strategy. Based on these findings, allowing the subjects to adopt the spontaneous strategy or training of the symmetric strategy could result in greater benefits for subjects with higher chronicity and higher functional levels, such as those evaluated in the present study.

References


Suppliers
a. EMG apparatus MP150WSW; Biopac System Inc, 42 Aeor Camino, Santa Barbara, CA 93117-3133.
c. SPSS 13.0 for Windows; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.