Effects of Limb Loading on Gait Initiation in Persons with Moderate Hemiparesis

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Purpose: To examine the immediate effect of symmetrical weight bearing (SWB) on temporal events of gait initiation (GI) patterns and timing and amplitude of lower distal limb muscles activity during GI in persons with hemiparesis.

Method: The study was a within-subjects design. Twelve persons with hemiparesis were recruited from the Veterans Affairs Brain Rehabilitation Research Center at the Malcom Randall Veterans Affairs, Gainesville, Florida. GI trials were performed from 4 beginning limb-loading conditions presented in a randomized order: (1) GI with the paretic limb during natural (asymmetrical) weight bearing (NWB); (2) GI with the nonparetic limb during NWB; (3) GI with the paretic limb during SWB; and (4) GI with the nonparetic limb during SWB. Temporal events of ground reaction forces (GRFs) and timing and amplitude of distal muscles activity were measured during GI trials in a motion analysis laboratory.

Results: There were no significant effects of SWB on the temporal events of GRFs and timing and amplitude of distal muscles activity when initiating gait with the paretic limb. Onset of tibialis anterior (TA) muscle was delayed significantly with less amplitude when initiating gait with the paretic limb in both NWB and SWB conditions. However, when initiating gait with the nonparetic limb, TA muscle on the paretic limb was activated normally with greater amplitude in both NWB and SWB conditions.

Conclusion: Initiating gait with the nonparetic limb as pregait activity may more effectively challenge the dynamic balance for a symmetrical gait pattern than the standard SWB in persons with hemiparesis.

Key words: gait initiation, physical therapy, rehabilitation, stroke, symmetry

Individuals with hemiparesis after stroke frequently have difficulty standing, walking, and moving from sit-to-stand (STS). One reason for these difficulties is the failure to generate adequate limb loading or active weight shift onto the paretic lower extremity. Inability of active weight shift onto the paretic limb induces a heavy limb load on the nonparetic limb while standing, during steady-state walking, and STS.

As a result, persons with hemiparesis commonly exhibit significant asymmetry during standing and walking with increased body weight bearing through the nonparetic limb. Therefore, a common rehabilitation goal for persons post stroke is to decrease the asymmetrical limb loading involving the paretic limb through weight-shifting or weight-bearing training.

Visual or audio signals by instruments have been used in biofeedback therapy to achieve standing symmetry. However, it is not known what the net effect of symmetrical weight bearing is in persons with hemiparesis who naturally show an asymmetrical weight bearing during quiet standing.

Although stroke rehabilitation programs stressing symmetrical weight bearing result in improved symmetry during static standing, the achievement of more symmetrical limb loading during standing may not be a prerequisite for independent transfer or unsupported walking. Standing asymmetry in persons with hemiparesis is associated with the primary neurological deficits caused by stroke as well as the secondary mechanical load of the distal lower limb due to uneven weight distribution while standing. Accordingly, minimizing the secondary biomechanical effect might be a separate training result independent of the motor recovery of the primary neurological deficits caused by stroke. As examples, Weinstein et al. indicated that improved static balance while standing was not transferred to the ability of steady-state walking in persons with hemiparesis.
Rogers et al\(^6\) reported that bending the knee in standing could not be transferred to motor control for the motion of the knee as a component of the walking pattern. Kirker et al\(^7\) showed that a normal pattern of hip muscle activation was identified in stepping, whereas the response of these muscles to a perturbation while standing remained grossly impaired and was compensated by increased activity of the contralateral muscles.

These previous findings support the view that achieving static balance while standing may not be necessary for starting dynamic gait training in persons with hemiparesis. Little attention, however, has been given to validate the clinical assumption that improved weight shift ability onto the paretic limb while static standing would lead to a more symmetrical and effective gait pattern in persons with hemiparesis. Therefore, an examination of the underlying motor control mechanism with respect to symmetrical weight bearing is critically important to understand how biomechanical changes interact with the impaired motor control accompanying a transition movement such as gait initiation (GI) in persons with hemiparesis. GI is known as a well-defined motor task often used to assess the effects of sensorimotor deficits because it involves a stereotyped pattern of muscle activity.\(^17,18\) In addition, GI is a single-axis gross movement in the sagittal plane at the ankle joint, generating momentum to move the body forward like an inverted pendulum.\(^19,20\) The simplicity of this single-axis task affords a salient means to access motor control by minimizing the influence of other joint variables.\(^16,20,21\) The task of GI begins with the inhibition of tonic soleus (Sol)\(^22\) activity followed by the onset of activation of the tibialis anterior (TA) of both the swing and stance limbs.

**Figure 1** shows the timing of kinematic and kinetic events during GI. This muscle sequencing pattern is responsible for the movement of the center of pressure (CoP) backward and toward the stance limb, which tends to propel the center of mass forward and toward the stance limb.\(^17\) According to Brunt et al,\(^17,18\) time to onset of electromyography (EMG) activity and force plate recordings, as well as time to swing toe-off, stance heel-off, swing heel strike, and stance toe-off for GI, all remain relatively invariant across slow, comfortable, and fast gait velocity in healthy persons. Even in an impaired sensory situation, kinetic temporal parameters are unchanged. Previous studies demonstrated that diminished single-limb postural instability by a tibial nerve block does not influence the change of kinetic temporal parameters during GI.\(^21\) Trimble et al\(^23\) reported that Sol H-reflexes were depressed to 37% of standing values during GI in a peroneal nerve-injured subject, even though no TA activity

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**Figure 1.** (A) Kinematic representation of the temporal events during gait initiation. (B) Horizontal (Fx) and vertical (Fz) ground reaction force and electromyographic recordings of bilateral tibialis anterior (TA) and soleus (Sol) from a single representative trial of gait initiation in a healthy subject. a. Light signal; b. stance Sol inhibition; c. swing and stance TA onset; d. onset of movement; e. swing limb toe-off; f. stance limb heel-off; g. swing limb heel strike; h. stance limb toe-off. The arrow indicates the direction of movement.
was observed. This finding is also consistent with the view that reciprocal inhibition of the Sol during GI, which normally involves TA activation, is independent of peripheral sensory input. Therefore, with respect to invariant temporal characteristics during GI, delayed or earlier temporal events during GI could be a biomechanical sign indicating movement compensation or impaired motor control in persons with hemiparesis.

Previous studies in persons with hemiparesis have demonstrated that during GI the magnitude of vertical and horizontal force generation on the ground varied depending on the initial loading when the paretic lower limb executed the first step.\(^5\,^6\) This finding raises the question of whether weighting shift onto the paretic limb while standing influences the motor pattern of step execution during GI.\(^7\) To investigate the underlying motor control mechanism, the present study examined the immediate effect of natural (asymmetrical) and symmetrical weight bearing on the temporal events of ground reaction forces (GRFs) and on timing and amplitude of lower distal muscle activity during GI in persons with hemiparesis. It was hypothesized that the relative temporal events of GRFs, the timing of TA and Sol muscle activity, and the amplitude of TA would be invariant across limb-loading conditions during GI in persons with hemiparesis.

**Methods**

**Design and participants**

The present study was a within-subjects design. Twelve subjects (7 males, 5 females) with unilateral hemiparesis were recruited from the database of the Veterans Affairs Brain Rehabilitation Research Center at the Malcom Randall Veterans Affairs, Gainesville, Florida. Subjects were required to be medically stable, capable of walking at least 5 m at their comfortable speed with guarded assistance, and standing independently for at least 30 seconds. Subjects who had a history of orthopedic or neurological conditions in addition to the stroke were excluded from the study. The ages ranged from 45 to 80 years (60.75 ± 9.85). Stroke duration ranged from 1 to 11 years (5.25 ± 3.14), which allowed time for natural recovery.\(^24\,^25\) The characteristics of subjects with hemiparesis are presented in Table 1. The University of Florida Institutional Review Board and the Veterans Affairs Subcommittee for Clinical Investigation approved this protocol. Each participant provided informed consent before participating in the study.

### Table 1. Description of subjects with hemiparesis

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age, years</th>
<th>Gender</th>
<th>Diagnosis</th>
<th>General locus</th>
<th>Stroke duration, years</th>
<th>CA (with cane, AFO)</th>
<th>FM balance</th>
<th>FM lower extremity score</th>
<th>Gait velocity (m/s)</th>
<th>Natural % BWD (P/NP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>56</td>
<td>M</td>
<td>Right infarct</td>
<td>Cerebrum 2</td>
<td>Yes (AFO) 12/14</td>
<td>32/34</td>
<td>0.85</td>
<td>48.9/51.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>62</td>
<td>M</td>
<td>Right infarct</td>
<td>Cerebrum 9</td>
<td>Yes 11/14</td>
<td>23/34</td>
<td>1.07</td>
<td>46.2/53.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>F</td>
<td>Left hem</td>
<td>Cerebrum 4</td>
<td>Yes 12/14</td>
<td>27/34</td>
<td>0.9</td>
<td>51.2/48.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>61</td>
<td>M</td>
<td>Left hem</td>
<td>Cerebrum 9</td>
<td>Yes 12/14</td>
<td>27/34</td>
<td>1.04</td>
<td>44.1/55.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>53</td>
<td>M</td>
<td>Left infarct</td>
<td>Brainstem 2</td>
<td>Yes (AFO) 9/14</td>
<td>16/34</td>
<td>0.36</td>
<td>20.4/79.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>67</td>
<td>M</td>
<td>Left infarct</td>
<td>Cerebrum 3</td>
<td>Yes (cane) 12/14</td>
<td>27/34</td>
<td>0.62</td>
<td>43.5/56.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7*</td>
<td>67</td>
<td>F</td>
<td>Right infarct</td>
<td>Cerebrum 8</td>
<td>Yes 10/14</td>
<td>32/34</td>
<td>0.82</td>
<td>37.4/62.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>64</td>
<td>F</td>
<td>Left infarct</td>
<td>Cerebrum 4</td>
<td>Yes (cane, AFO) 5/14</td>
<td>16/34</td>
<td>0.23</td>
<td>43.1/56.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9*</td>
<td>80</td>
<td>M</td>
<td>Left infarct</td>
<td>Cerebrum 1</td>
<td>Yes 10/14</td>
<td>31/34</td>
<td>0.96</td>
<td>42.2/57.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>71</td>
<td>M</td>
<td>Left infarct</td>
<td>Cerebrum 11</td>
<td>Yes 14/14</td>
<td>32/34</td>
<td>1.25</td>
<td>59.8/40.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>51</td>
<td>F</td>
<td>Left infarct</td>
<td>Cerebrum 4</td>
<td>Yes 10/14</td>
<td>15/34</td>
<td>0.68</td>
<td>42.6/57.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>52</td>
<td>F</td>
<td>Right infarct</td>
<td>Cerebrum 6</td>
<td>Yes (cane, AFO) 9/14</td>
<td>14/34</td>
<td>0.36</td>
<td>40.8/59.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Subject 7 had second ipsilateral stroke; Subject 9 had a lacunar infarct. Gender: M = male; F = female. CA = community ambulation; AFO = ankle foot orthosis; FM = Fugl-Meyer; BWD = body weight distribution; P = paretic limb; NP = nonparetic limb; Hem = hemorrhage.
Effects of Limb Loading on Gait Initiation

Equipment

EMG recording electrodes consisted of 2 silver-silver chloride 1-cm diameter electrodes embedded in an epoxy-mounted preamplifier system (× 35) whose centers were spaced 2 cm apart. Conductive paste was applied to the surface electrodes. After the subject’s skin was cleaned with alcohol, surface electrodes were applied to the muscle belly of the TA and Sol of both lower extremities and held in place over the skin by adhesive tape. A reference electrode was attached to the medial aspect of the tibia. Placement of the electrodes was confirmed by the myoelectric signal during isometric muscle contraction. The EMG signals were band-pass filtered (20 Hz to 4 KHz; Therapeutics Unlimited, Iowa City, Iowa) and full-wave rectified online. Final amplification was 10 k. Two force platforms (Advanced Mechanical Technology Inc, Watertown, Massachusetts), embedded in a level walkway (10 m in length and 1.22 m in width), were used to identify the relative temporal events of GRF during GI. Processed EMG and amplified force platform signals were sampled online at a rate of 1000 Hz (BIOPAC System, Goleta, California). F-scan, paper-thin sensors (Tekscan Inc, South Boston, Massachusetts), was placed in the shoes to measure vertical GRF while subjects were standing. F-scan in the shoe system was processed at 120 to 150 Hz to capture foot pressure images. The output from the F-scan system was projected onto a screen at the end of the walk so that subjects received real-time feedback about the weight borne by each lower extremity. This did not interfere with the subject’s normal gait.

Procedure

Fugl-Meyer lower extremity and gait velocity

The lower extremity and balance subsections of the Fugl-Meyer motor assessment were performed on the hemiparetic subjects prior to the performance of GI to provide a global indicator of motor impairment. Subjects with hemiparesis donned the standard tennis footwear, and gait velocity was measured by having each subject walk 5 m. The time was measured using a stopwatch. No assistive devices such as a cane or an ankle brace were provided to the subjects to eliminate the effect of those devices during walking.

Symmetrical body weight limb-loading training

Data were recorded prior to GI testing to document the degree of asymmetry achieved. At the beginning of each trial, the subject was asked to watch the screen projected onto the wall in front of him or her that provided immediate feedback concerning the weight distribution or load on each lower limb from the F-scan system (Figure 2). Each subject exhibited different limb-loading conditions during natural, quiet standing without visual feedback by the F-scan system. The subject was asked to weight shift to achieve equal weight distribution with visual feedback. The subject practiced the symmetrical position 5 times to gain comfort.

Gait initiation

Next, each subject stood with 1 foot on each force plate, and the starting position was marked by drawing a line at the toe end of the shoe on the force plate. The subject performed the following conditions of limb-loading distribution prior to executing a step in a randomized order: (1) GI with the paretic limb during natural (asymmetrical) weight bearing; (2) GI with the nonparetic limb during natural weight bearing; (3) GI with the paretic limb during symmetrical weight bearing; and (4) GI with the nonparetic limb during symmetrical weight bearing. Subjects began walking at their comfortable speed when they saw a visual cue (light). They were asked to initiate gait as quickly as possible after the visual cue and to return to the marked position after each trial of GI. Subjects completed 5 trials with guarded assistance in each condition. The performance of GI was recorded on videotape. Rest was provided at any point during the testing, if requested. Otherwise, subjects were allowed to sit and rest between test conditions until they were comfortable with proceeding. This experiment took approximately 2 hours.

Data processing

For primary data analysis, the body weight distribution prior to a step execution was
accurately calculated using the F-scan software. The software calibrated each subject’s body weight as 100%. The weight distribution, depending on limb-loading conditions, was obtained from the F-scan system. We referred to the GRFs and EMG to determine the relative temporal events of GI. To normalize the temporal parameters of GI according to each subject, we considered the time from the visual cue to stance limb toe-off as 100% of the GI cycle (Figure 1). Measured relative temporal parameters included the following: (1) time to TA onset in the swing limb, (2) time to TA onset in the stance limb, (3) time to movement onset, (4) time to swing limb toe-off, (5) time to stance limb heel-off, (6) time to swing limb heel strike, and (7) the interval between Sol inhibition and TA activation on the stance limb.

The onset and offset of muscle activation were determined using an interactive cursor with 1-ms resolution. Onset of muscle activity occurred when the activity level exceeded the mean (the baseline of muscle activity for 30 ms plus 2 SD). Offset of muscle activation was defined as when the activity level returned to the mean plus 2 SD. The peak TA muscle activity was obtained between visual cue and swing limb toe-off. To normalize the muscle amplitude, we considered the peak value of TA muscle during 1 gait cycle after stance limb toe-off as 100%. The root mean square was used as a smoothing method of the surface EMG. The signal was processed using a moving average of 20 data points.

Data normalization

The Shapiro-Wilk test was used to determine normality of all initial measures of force plates and EMG. Log transformations were applied to normalize the relative temporal and EMG parameters for the following variables: (1) time to TA onset in the swing limb, (2) time to TA onset in the stance limb, (3) time to swing limb heel strike, (4) the interval between Sol inhibition and TA activation on the stance limb, and (5) peak amplitude of the stance limb TA activity in persons with hemiparesis.

Statistical analysis

Multivariate analysis of variance techniques with 1 fixed factor (limb loading) were used to identify the multivariate effect of loading for dependent variables. A multivariate $F$ value was obtained from Wilks lambda. To know exactly which limb-
loading conditions means were significantly different from other limb-loading means, we used post hoc univariate F tests. The least significant difference (LDS) test was used for multiple comparisons with regard to side of initiation (paretic vs nonparetic) and limb-loading conditions (symmetrical vs natural). The dependent variables were the following parameters: (1) time to TA onset in the swing limb, (2) time to TA onset in the stance limb, (3) time to movement onset, (4) time to swing limb toe-off, (5) time to stance limb heel-off, (6) time to swing limb heel strike, (7) the interval between Sol inhibition and TA activation on the stance limb, (8) peak amplitude of the swing limb TA, and (9) peak amplitude of the stance limb TA during GI. The P value of less than .05 was considered to indicate significant differences. All data were analyzed using the Statistical Package for the Social Sciences (SPSS 17 for Windows; SPSS Inc, Chicago, Illinois).

Results

Symmetrical weight bearing prior to GI

The subjects showed an average 43.3 percent body weight (%BW) (±9.3) (Fz) distribution on the paretic limb and 56.7 %BW (±9.3) on the nonparetic limb during quiet natural standing without visual feedback (Table 1). Most of the subjects successfully achieved symmetrical body weight limb loading, 50.60 %BW (±5.35) on the paretic limb and 50.42 %BW (±5.40) on the nonparetic limb during the 3 trials in response to verbal instructions and visual weight distribution feedback from F-scan system.

Temporal events of GRFs and timing and amplitude of distal muscles during GI

The multivariate main effect (Wilks lambda) for limb-loading conditions was significant ($F_{24,67} = 2.310$, $P = .004$). There were no significant changes on the relative temporal events of GRFs, but timing and amplitude of TA muscle across limb-loading conditions during GI were significant. The univariate main effects were significant for time to TA onset in the swing limb ($F_{3,30} = 15.527$, $P = .000$), time to TA onset in the stance limb ($F_{3,30} = 2.991$, $P = .047$), and peak amplitude of the swing limb TA ($F_{3,30} = 3.755$, $P = .021$). The onset of TA muscle on the paretic side was delayed about 20% GI when the paretic limb was the swing limb compared with TA on the nonparetic side when the nonparetic limb was the swing limb during GI (Table 2).

LSD tests showed a significant effect of side of initiation (paretic vs nonparetic) and limb-loading conditions (symmetrical vs natural) during GI. First, with respect to side of initiation, initiating gait with the nonparetic (swing) limb caused the normal timing and greater peak amplitude of TA muscle on the paretic (stance) limb in persons with hemiparesis ($P < .05$). However, there were no

### Table 2. Percentage of gait initiation (GI) cycle of selected temporal events and peak electromyography amplitude of the tibialis anterior (TA)

<table>
<thead>
<tr>
<th>Limb loading</th>
<th>GI with the paretic limb during NWB</th>
<th>GI with the nonparetic limb during NWB</th>
<th>GI with the paretic limb during SWB</th>
<th>GI with the nonparetic limb during SWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swing TA onset (%)*</td>
<td>44.29 (15.76)</td>
<td>24.71 (10.91)</td>
<td>46.79 (6.39)</td>
<td>28.34 (12.19)</td>
</tr>
<tr>
<td>Stance TA onset (%)*</td>
<td>24.60 (13.41)</td>
<td>23.51 (10.72)</td>
<td>27.12 (11.31)</td>
<td>27.90 (9.54)</td>
</tr>
<tr>
<td>Onset of movement (%)</td>
<td>19.42 (4.48)</td>
<td>19.67 (3.62)</td>
<td>22.90 (7.84)</td>
<td>25.45 (4.72)</td>
</tr>
<tr>
<td>Swing heel-off (%)</td>
<td>55.48 (5.48)</td>
<td>56.39 (5.09)</td>
<td>57.87 (6.90)</td>
<td>58.57 (4.25)</td>
</tr>
<tr>
<td>Stance heel-off (%)</td>
<td>69.76 (2.58)</td>
<td>66.03 (7.67)</td>
<td>69.03 (5.77)</td>
<td>64.97 (7.10)</td>
</tr>
<tr>
<td>Swing heel strike (%)</td>
<td>80.98 (3.23)</td>
<td>75.63 (10.20)</td>
<td>81.19 (4.53)</td>
<td>76.86 (9.15)</td>
</tr>
<tr>
<td>Sol/TA interval (%)</td>
<td>3.046 (1.26)</td>
<td>3.18 (0.96)</td>
<td>2.72 (0.77)</td>
<td>3.39 (0.82)</td>
</tr>
<tr>
<td>Peak amplitude of swing TA (%)*</td>
<td>41.70 (25.16)</td>
<td>75.81 (36.35)</td>
<td>43.54 (26.32)</td>
<td>75.29 (29.26)</td>
</tr>
<tr>
<td>Peak amplitude of stance TA (%)</td>
<td>68.21 (22.90)</td>
<td>73.92 (44.53)</td>
<td>79.76 (50.36)</td>
<td>68.40 (43.12)</td>
</tr>
</tbody>
</table>

Note: Percent GI is taken from the visual cue to toe-off stance limb; percent of maximum TA activity is taken during 1 gait cycle after stance limb toe-off during GI. NWB = natural weight bearing; SWB = symmetrical weight bearing; Sol = soleus.

*The arrow indicates percent GI change of timing and peak amplitude of TA muscle on the paretic limb.

*Statistically significant differences among limb-loading conditions, $P < .05$. 

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significant effects of initiating gait with the paretic limb on timing and amplitude of TA muscle on the paretic limb. Second, with respect to limb-loading conditions, initiating with the nonparetic (swing) limb caused a significantly delayed muscle excitation of TA on the paretic (stance) limb while in the symmetrical weight-bearing condition \((P < .05)\). However, there were no significant effects of initiating gait with the paretic (swing) limb on timing and amplitude of TA muscle on the paretic (swing) limb while in the symmetrical weight-bearing condition \((P > .05)\).

**Discussion**

The primary finding of this study was that impaired TA muscle on the paretic limb of persons with hemiparesis was activated in a normal sequence of muscle excitation, with greater amplitude when the paretic limb was loaded to allow the nonparetic limb to initiate the first step (Table 2 and Figure 3). In Figure 3, the ground reaction force (swing Fz) exhibits an increase with loading in preparation for executing a step. In Figures 3A and 3C, when the subject initiated a step with the paretic limb, the activation pattern of the swing TA is delayed in onset. According to Brunt et al,\(^{17,18}\) both TA muscles of swing and stance limbs would burst, disrupting balance in preparation of step execution. In Figures 3B and 3D when the subject initiated a step with the nonparetic limb, note the simultaneous burst of TA activity aligned on the arrow. The arrow corresponds to the onset of preparatory movement of the center of pressure for stepping. However, no temporal sign arose on the paretic limb related to GI with the paretic limb while symmetrical weight bearing in the present study. This finding indicates that symmetrical weight bearing in persons with hemiparesis may not affect the temporal events of GI patterns and timing and amplitude of TA muscle activity necessary for GI. Thus, achieving symmetrical weight bearing while static standing may not be a prerequisite for the earlier start of dynamic gait training. Brunt et al\(^{5}\) reported that the inability to generate forward body progression appears related to the absence of TA activity when movement occurs. Thus, patients with symmetrical limb loading while standing showed increased forward momentum with TA activity on the paretic limb during GI.\(^{5}\) However, this study showed that improvement of standing symmetry during GI did not induce any adequate muscle activity on the impaired TA muscle for the effective weight shift necessary during GI. This finding indicates the sensory information accompanying symmetrical limb loading while static standing may not link with the central command system to control the motor performance during GI.

This study shows that when initiating gait with the nonparetic (swing) limb, the paretic TA muscle (stance) was activated at the normal relative timing of percent GI cycle (Figure 3). In addition, when initiating gait with the nonparetic limb, the amplitude of the TA muscle on the paretic (stance) limb was significantly increased about 27% to 36% compared with the paretic limb as swing limb in both natural and symmetrical limb-loading conditions (Table 2). This finding implies that initiating gait with the nonparetic limb might result in more effective backward movement of CoP,\(^{30}\) which is associated with appropriate timing of the TA muscle on the paretic limb during GI.\(^{31}\) This study demonstrates that increased amplitude of the TA muscle on the paretic limb was strongly related to the timing of TA muscle activity while initiating the first step with the nonparetic limb during GI. When starting with the nonparetic limb, the CoP must be shifted to the paretic limb, and the paretic limb should play a role as a support limb during GI. Hesse et al\(^{8}\) indicated that the CoP in persons with hemiparesis was already shifted to the nonparetic limb prior to step execution, whereas CoP is located midway between both feet in healthy people. Although starting GI with the nonparetic limb, the forward momentum was weaker than when starting with the paretic limb,\(^{5,8}\) and the paretic limb may have a greater potential to be activated for the body forward progression as a support limb.

The relative timing of swing limb heel strike was not altered at all by any limb-loading conditions. Breniere et al\(^{20,32}\) indicated that the time to first step remained invariant across slow, normal, and fast walking speeds during GI, because during this phase the body behaves as an inverted pendulum.
and the period of first step might be determined
by the biomechanical factors. The relative timing
of swing limb heel strike in the present study was
similar to the findings of Brunt et al\textsuperscript{18} even when
comparing an older population (41 to 71 years in
this study) with the younger population (18 to 40
years). Thus, time to swing limb heel strike might
be an invariant temporal marker determined by
the biomechanical factors\textsuperscript{20} rather than the central
programming of GI.

The interval between Sol inhibition and TA
activation during the time from the visual cue to
movement onset remained invariant across limb-
loading conditions in persons with hemiparesis.
When a subject initiates walking,\textsuperscript{17} steps over an
obstacle,\textsuperscript{17} or flexes the knee,\textsuperscript{6} the Sol muscle is
inhibited bilaterally, and a large burst of TA activity
is required to generate the backward movement
momentum.\textsuperscript{20,33,34} A quick loading of the swing
limb and unloading of the stance limb comes with
these patterns of muscle activations during GI.\textsuperscript{31,34} This sequential synergistic interaction between Sol inhibition and TA activation has been considered a centrally mediated motor program.\textsuperscript{31} According to Cordo et al.,\textsuperscript{35} programmed movement commands determine the temporal sequencing of muscle activity. For instance, the inhibition of tonic Sol followed by the onset of TA represents central programming to execute the step from quiet standing because the interval between Sol inhibition and TA activation remains invariant across intended gait velocities.\textsuperscript{30} Crenna et al\textsuperscript{30} found that the interval between Sol inhibition and TA activation for all speeds of GI averaged about 100 ms. Brunt et al\textsuperscript{17} reported that the interval ranged from 46 to 51 ms regardless of GI speed. This study also showed the interval between Sol inhibition and TA activation ranged from 49 to 61 ms in persons with hemiparesis. Long loop reflexes take more than 100 ms for sensory feedback signals to reach the cortex in the performance of rapid movements.\textsuperscript{36,37} This finding suggests that the programming of temporal muscle sequence during GI is independent of peripheral sensory input, depending on limb-loading conditions as well.

**Conclusion**

According to Hill et al,\textsuperscript{38} only 7% of all stroke survivors are able to walk independently in the community. Even among those who achieve independent walking, most of them with residual motor disability are not able, for instance, to walk independently in a crowded shopping center.\textsuperscript{39}

Active weight shifting is an important factor in determining the degree of walking ability in persons with hemiparesis. However, this study suggests that symmetrical weight bearing while standing may induce a better postural alignment, but it may not affect the temporal events of GI patterns and timing and amplitude of TA muscle activity necessary for GI. The task of GI requires a transition from a relatively large base of support in bipedal stance to a small base of support in single-limb stance.\textsuperscript{30} The body’s center of mass moves outside of the base of support during GI. Therefore, initiating gait with the nonparetic limb challenges dynamic balance in a manner similar to the balance required during gait in persons with hemiparesis. As a result, this study suggests that initiating gait with the nonparetic limb as a pregait activity may more effectively challenge the dynamic balance for a symmetrical gait pattern than the standard standing weight shifting in persons with hemiparesis.

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