Locomotor Training Improves Daily Stepping Activity and Gait Efficiency in Individuals Poststroke Who Have Reached a “Plateau” in Recovery

Jennifer L. Moore, PT, NCS; Elliot J. Roth, MD; Clyde Killian, PhD, PT; T. George Hornby, PhD, PT

Background and Purpose—Individuals with chronic stroke often demonstrate a “plateau,” or deceleration of motor recovery, which may lead to discharge from physical therapy (PT). However, numerous studies report improvements in motor function when individuals are provided intensive practice of motor tasks. We suggest that reduced task-specific walking practice during clinical PT contributes to limited gains in ambulatory function in those with a perceived plateau poststroke, and suggest that further gains can be realized if intensive stepping, or locomotor training (LT) is provided after discharge.

Methods—Twenty subjects with chronic stroke completed a repeated baseline measures, randomized crossover trial in which walking performance was assessed during the last 4 weeks of clinical PT before discharge secondary to reaching a plateau, followed by 4 weeks of intensive LT and 4 weeks of no intervention. Outcome measures included clinical and physiological (metabolic) measures of walking overground and on a treadmill, and measures of daily stepping activity in the home and community, including during clinical PT and subsequent LT sessions.

Results—Stepping practice was more than 4-fold higher during LT versus clinical PT sessions, with significant improvements in daily stepping and gait efficiency only after LT. Changes in daily stepping after clinical PT and intensive LT were correlated (P<0.001) with the amount of stepping practice received during these interventions.

Conclusions—Intensive LT results in improved daily stepping in individuals poststroke who have been discharged from PT because of a perceived plateau in motor function. These improvements may be related to the amount and intensity of stepping practice. (Stroke. 2010;41:129-135.)

Key Words: functional recovery ■ physiotherapy ■ stroke recovery ■ locomotion

Despite initial improvements in motor function in individuals early poststroke, patients often demonstrate a “plateau,” or deceleration of motor recovery in the chronic stages (ie, > 6 months) which often leads to discharge from physical therapy (PT). Current data suggest that the physiological substrates underlying motor recovery after supraspinal injury are reduced in the latter stages posts insult and could contribute to this apparent “plateau.” However, numerous studies have demonstrated that practice of specific motor tasks enables clinically significant improvements in function after the presumed “plateau” phase. Several theories underlying this perceived “plateau” in the clinical setting have been articulated, although few studies have directly addressed this issue.

One hypothesis to explain this “plateau” in motor function poststroke is the provision of minimal task-specific practice in the clinical setting. In animal models of cortical injury and humans with hemiparesis poststroke, the amount of volitional motor practice can markedly influence motor recovery. For recovery of walking function, locomotor training (LT) performed on a treadmill with partial weight support is one intervention which can increase the amount and intensity of stepping practice. LT facilitates improvements in overground walking speed and timed walking distance in individuals poststroke which may be related to improved muscle activation or metabolic measures of peak aerobic capacity or gait efficiency. Preliminary estimates indicate an average of ≈4000 steps performed during 1-hour LT sessions, which may contribute to the observed clinical and physiological benefits. Unfortunately, data from single- and multi-center studies suggest that the amount of stepping practice provided to patients poststroke during actual clinical PT sessions averages <400 steps. Decreased practice may limit recovery of motor function and contribute to the perceived “plateau,” whereas further improvements may be realized if intensive interventions were provided.
The primary goals of the present study were 2-fold. The first was to quantify the changes in daily stepping and walking performance in individuals with chronic hemiparesis poststroke with a primary goal to improve walking ability, but scheduled for discharge from clinical PT secondary to reaching a plateau in motor function. Our second goal was to determine whether those same individuals poststroke could realize significant improvements in locomotor function when provided intensive LT after discharge from clinical services. Using a repeated measures crossover design, we quantified physiological and functional measures of locomotor function in subjects with chronic hemiparesis poststroke during the last 4 weeks of PT, and subsequently after 4 weeks of LT. Daily stepping activity was recorded throughout the study, including during PT and LT sessions to identify the amount of stepping practice provided during these interventions. We hypothesized that the amount of stepping practice during clinical PT may contribute to the perceived “plateau” in walking ability, whereas higher doses provided during intensive LT would facilitate improved walking ability.

Methods
All procedures were approved by the Institutional Review Board of Northwestern University/Rehabilitation Institute of Chicago. All subjects provided written informed consent. Subjects with hemiparesis of ≥6 months duration who were attending PT after unilateral supratentorial stroke were recruited. All subjects were required to walk >10 m overground without physical assistance at speeds ≥0.9 m/s at their self-selected velocity (SSV), and required medical clearance to participate. Two additional inclusion criteria consisted of: (1) a primary stated goal to improve walking ability; and (2) enrolled approximately 1 month before termination of PT services secondary to decreased gains in function, as stated by the treating clinical therapist (ie, subjects with limited insurance coverage for PT services were not eligible). Exclusion criteria included presence of lower extremity contractures, significant osteoporosis, cardiovascular instability, previous history of peripheral or central nervous system injury, cognitive or communication impairment; and inability to adhere to study requirements. Previous data using LT10 and conventional interventions16 provided estimates of effect sizes for improvements in SSV, where 20 subjects would provide 99% power.

Experimental Protocol
A randomized crossover study design with ≥2 repeated baseline measures (A1 and A2) of walking performance during the last 4 weeks of clinical PT followed by randomization to immediate LT for 4 weeks and then a delay period (immediate LT group) or a delay period after 4 weeks of LT (delayed LT group). Assessments were made after completion of each period (A3 and A4). Shaded area indicates when LT occurred.

Assessment 1 (A1): initial assessment
Assessment 2 (A2): post-clinical PT
Assessment 3 (A3): post-LT or delay
Assessment 4 (A4): post-delay or LT

Figure 1. Schematic of the study design, with ≥2 repeated baseline measures (A1 and A2) of walking performance during the last 4 weeks of clinical PT followed by randomization to immediate LT for 4 weeks and then a delay period (immediate LT group) or a delay period after 4 weeks of LT (delayed LT group). Assessments were made after completion of each period (A3 and A4). Shaded area indicates when LT occurred.

Subjects
Subjects with hemiparesis of ≥6 months duration who were attending PT after unilateral supratentorial stroke were recruited. All subjects were required to walk >10 m overground without physical assistance at speeds ≥0.9 m/s at their self-selected velocity (SSV), and required medical clearance to participate. Two additional inclusion criteria consisted of: (1) a primary stated goal to improve walking ability; and (2) enrolled approximately 1 month before termination of PT services secondary to decreased gains in function, as stated by the treating clinical therapist (ie, subjects with limited insurance coverage for PT services were not eligible). Exclusion criteria included presence of lower extremity contractures, significant osteoporosis, cardiovascular instability, previous history of peripheral or central nervous system injury, cognitive or communication impairment; and inability to adhere to study requirements. Previous data using LT10 and conventional interventions16 provided estimates of effect sizes for improvements in SSV, where 20 subjects would provide 99% power.

| Table 1. Demographic and Baseline Characteristics |
|-----------------|---------|---------|
| Age, y          | 50±15   |         |
| Gender, male/female | 14/6    |         |
| Race, white/other | 8/12    |         |
| Side of paresis, left/right | 16/4 |         |
| Ischemic/hemorrhagic stroke, n | 10/10 |         |
| Duration post-injury, months | 13±8 |         |
| Ankle foot orthosis, n | 12 |         |
| Assistive device, n | 16 |         |
| Moderate/severe gait limitations, n | 13/7 |         |

Mean±SD provided for ratio data.

<table>
<thead>
<tr>
<th>Table 2. Changes (Mean±SD) in Walking Measures During Clinical PT, Determined From the 1st (A1) to 2nd Assessments (A2)</th>
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<tbody>
<tr>
<td>Primary Measures</td>
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<tr>
<td>Self-selected velocity, m/s</td>
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<tr>
<td>Fastest velocity, m/s</td>
</tr>
<tr>
<td>12-minute walk, m</td>
</tr>
<tr>
<td>O2cost, ml/kg/km</td>
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<tr>
<td>peak treadmill speed, m/s</td>
</tr>
<tr>
<td>VO2peak, ml/kg/min</td>
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<tr>
<td>Berg Balance Scale</td>
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<td>Timed Up and Go, s</td>
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</table>
determined by the treating therapist without consultation from study investigators.

After discharge from PT and adherence to study guidelines, quantitative assessments were repeated (assessment 2: A2). If therapists extended PT services beyond the scheduled termination date, subjects were reassessed every 4 weeks until discharge, with A1 considered their assessment at 4 weeks before discharge. Subjects were stratified into those with moderate (SSV 0.5 to 0.9 m/s) versus severe (>0.9 m/s) gait limitations, and randomized to receive 4 weeks of intensive LT immediately after discharge from clinical PT (immediate LT group), or 4 weeks after discharge from clinical PT (delayed LT group). Subjects were randomized using sealed envelopes concealed from view.

The immediate LT group was provided 4 weeks of intensive LT after discharge from clinical PT, which consisted of high-intensity stepping practice on a motorized treadmill while wearing an overhead harness attached to a safety system. LT was performed at the same frequency as PT (2 to 5 days/wk) at the highest tolerable speed, with velocity increased in 0.5-kmph increments until subjects’ heart rate reached 80% to 85% of age-predicted maximum or until the subjects’ Rating of Perceived Exertion increased to 17 on the Borg scale. Up to 40% partial body weight support using a counterweight system attached to the safety harness was provided for those subjects who walked <0.2 m/s overground, and was reduced in 10% increments as tolerated. Subjects held onto the handrail for balance only, and therapists did not provide manual assistance to improve intralimb kinematics, but rather focused on increasing intensity and amount of stepping practice as tolerated. After completion of LT, subjects were reassessed (assessment 3: A3), and again after a delay of 4 weeks after completion of LT (assessment 4: A4).

The delayed LT group was also assessed 4 weeks before and after termination from clinical PT (A1 and A2), but did not receive LT or any other interventions for 4 weeks after termination of clinical PT.
Outcomes

Outcome measures included clinical measures of walking performance over short and long distances, peak treadmill velocity during a graded walking test, metabolic responses during continuous overground and treadmill walking, and stepping activity in the home and community, including during PT and LT sessions. Gait speed at SSF or fastest-possible velocity (FV) was collected using the GaitMat II (Equitest Inc). Timed walking distance at SSF was determined using the 12-minute walk test and recorded each minute, with cardiorespiratory/metabolic data collected simultaneously using a portable, indirect calorimetry system (K4b2, Cosmed, Inc). After subtraction of baseline oxygen consumption (VO2, ml/kg/min) recorded during quiet sitting, gait efficiency (or O2cost) during continuous walking was determined by dividing the average VO2 per minute of the 12-minute walk test by the average gait speed recorded during each minute of the test or until the subject required a rest break. Peak treadmill velocity and peak VO2 (VO2 peak) were determined using a modified graded exercise testing protocol, in which subjects walked at 0.1 m/s for 2 minutes, with speed increased by 0.1 m/s every 2 minutes as tolerated. Testing was terminated with gait instability at higher speeds or when heart rate reached 85% of age predicted maximum, or RPE >17.15 and the highest VO2 averaged over 1 minute was recorded. Additional measures included the Berg Balance Scale (BBS) and the Timed Up and Go (TUG).

Daily stepping activity in the home and community, including during PT and LT sessions, was determined using a Step Activity Monitor (StepWatch, Cyma Inc), a portable lightweight microprocessor-based accelerometer/pedometer placed on the unpaired leg, and used previously in this population.19 Subjects were required to wear the pedometer for 90% of their waking hours throughout the study and document precise times of clinical PT with a daily journal, which was later confirmed by PT documentation. Subjects who did not wear the pedometer as required were excluded from the study. Stepping activity was recorded each minute and averaged per day, with ≥5 days of stepping activity determined before and after clinical PT and intensive LT to assess changes with each intervention. Stepping activity (ie, practice) provided during PT and LT sessions were recorded and averaged, and verified using therapists’ documentation and subjects’ journals.

Data and Statistical Analysis

Demographics or outcome measures at each assessment period (A1 to A4) are presented as mean±SD in the text and tables, with mean±SE in the figure. Data were assessed for normality (Kolmogorov-Smirnov), and baseline characteristics were compared between immediate and delayed LT groups using unpaired t tests and Mann–Whitney U tests as appropriate. Statistical analyses focused on changes in outcome measures during PT, during LT versus delay periods, and differences in stepping activity during and after the PT and LT sessions. Differences during the last 4 weeks of clinical PT (A1 to A4) were analyzed using paired comparisons (t test, Wilcoxon signed rank) as appropriate. Changes in outcome measures during the intensive LT versus delay period (A1 to A4) were determined using a 2-way repeated measures ANOVA with main effects of group (immediate versus delayed LT) and repeated for time/assessment; effects of gait impairment were not performed because of low numbers of severely impaired subjects. Post hoc single factor repeated measures ANOVA and Tukey-Kramer tests were performed with significant main effect of time or interaction effects. BBS data were analyzed using Friedman tests with post hoc Wilcoxon tests. Daily stepping was averaged over the 4 weeks of PT and LT, with separate analysis of stepping activity during PT and LT sessions. Daily stepping for at least 5 days in the home and community was determined before and after each intervention period (PT and LT). Correlation and simple regression analyses were used to determine the relationship between amount of stepping practice received during PT/LT, and the changes in daily stepping after each intervention. Significance was set at α=0.05.

Results

Thirty of 68 individuals referred to the study fulfilled inclusion criteria and were enrolled, although 10 did not complete the protocol because of noncompliance with study requirements (ie, not wearing accelerometer, n=5), early discharge from clinical PT (n=2), orthopedic injury which limited walking (n=1), or previous diagnosis of secondary neurological injuries (n=2). Seven of 20 subjects presented with severe gait impairments (4 in the immediate LT group, 3 in delayed LT group). Demographics and clinical characteristics are provided in Table 1, with no differences between groups.

Changes in outcome measures were assessed before and after the last 4 weeks of clinical PT in subjects with therapist-report of reduced gains in locomotor function. Daily stepping averaged 3822±2805 steps/d before the last 4 weeks of clinical PT, and was not different after discharge (3846±2932 steps/d, P=0.88). Average daily stepping during clinical PT was 4207±2922, with a mean of 886±852 steps performed during PT sessions. Changes in other outcome measures are shown in Table 2, with improvements in

Table 3. Changes (Mean±SD) in Walking Measures Before and After Locomotor Training (LT) and Delay Period per Training Group (Immediate Versus Delayed LT)

<table>
<thead>
<tr>
<th>Time Effects</th>
<th>Time×Group Interaction</th>
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<tbody>
<tr>
<td>Immediate LT</td>
<td>Delayed LT</td>
</tr>
<tr>
<td>A1</td>
<td>A3</td>
</tr>
<tr>
<td>Self-selected velocity, m/s</td>
<td>0.58±0.27</td>
</tr>
<tr>
<td>Fastest velocity, m/s</td>
<td>0.80±0.40</td>
</tr>
<tr>
<td>12 minutes walk, m</td>
<td>413±231</td>
</tr>
<tr>
<td>O2cost, ml/kg/km</td>
<td>410±386</td>
</tr>
<tr>
<td>Peak treadmill speed, m/s</td>
<td>1.0±0.3</td>
</tr>
<tr>
<td>VO2peak, ml/kg/min</td>
<td>17±3.2</td>
</tr>
<tr>
<td>Berg Balance Scale</td>
<td>46±15</td>
</tr>
<tr>
<td>Timed Up and Go, s</td>
<td>21±12</td>
</tr>
</tbody>
</table>

Outcomes at 2nd (A2), 3rd (A3), and 4th (A4) assessment periods are provided with bold areas indicating when LT was provided.

(ie, delay period). After this 4 week delay, subjects were reassessed before (A3) and after (A4) 4 weeks of intensive LT as described above. The study design is illustrated in Figure 1.
clinical measures of walking performance (SSV, FV, and 12-minute walk), but no change in other assessments.

During the 4 weeks of LT performed after discharge from PT (immediate and delayed groups), daily stepping averaged 5560±2801, with 3896±3906 steps performed during LT sessions; both values were significantly greater than stepping activity performed during clinical PT (both *P*<0.001; Figure 2A and 2B). Daily stepping activity performed after LT sessions increased 25% (3692±2557 to 4590±3027, *P*<0.001) from pre-LT values and was significantly different from changes observed during clinical PT (*P*<0.01; Figure 2C). Further analysis revealed that the average stepping dosage (# steps/session) provided to subjects each PT or subsequent LT session was correlated with improvements in daily stepping in the home and community (*r* =0.57, *P*<0.001; Figure 2D). A similar relation between stepping dosage and improvements in daily stepping was observed when average stepping practice/wk during PT/LT sessions was calculated to account for differences in training frequencies across subjects (*r* =0.55, *P*<0.001).

Laboratory-based walking measures demonstrated variable changes after intensive LT and delay periods, with outcomes detailed in Table 3 and selected variables described in Figure 3. For example, SSV and FV improved throughout A2 to A4 (main effect of time) despite discharge from clinical PT secondary to the presumed “plateau” with a significant time×group interaction only for FV. Posthoc testing indicated significant increases in SSV for the delay group during the “delay” period and in FV in the immediate group during LT. For 12-minute walk (Figure 3A), total distance increased significantly throughout A2 to A4 with no interactions, with significant improvements from A2 to A3 for both groups.

For metabolic and treadmill-based measures, significant main and interaction effects were demonstrated for O$_2$cost and peak treadmill speed, but not VO$_2$ peak (Figure 3B through 3D). Specifically, the former variables improved for either immediate or delayed LT groups during LT sessions only. Notably, O$_2$cost assessed during the 12-minute walk test
improved substantially despite variable changes in 12-minute walk distance after LT.

Changes in BBS and TUG were observed throughout A2 to A4, although there was no specific benefit of LT over the delay period.

**Discussion**

Our results indicate that improvements in walking performance could be elicited in individuals with hemiparesis poststroke when provided intensive LT, even after discharge from PT secondary to therapist report that subjects reached a “plateau” in motor function. Significant improvements in clinical measures of walking performance (SSV, FV, and 12-minute walk) were observed at each assessment, although there was no greater improvement after LT beyond changes observed during clinical PT or the delay period. Rather, O_{2}-cost assessed during the 12-minute walk improved only after LT, despite inconsistent improvements in distance. Daily stepping also improved after LT with no improvement observed after clinical PT.

Gains in daily stepping and gait efficiency after intensive LT appear to be related to stepping dosage. The amount of stepping practice performed during PT in this study was more than 2× greater than previous estimates during conventional PT,^{14,15} but was still <25% of stepping practice performed during subsequent LT sessions. Differences in stepping dosage appear to contribute to improvements in daily stepping, and is likely contributed to changes in O_{2}-cost after LT sessions.^{13} Gait efficiency is thought to strongly influence community walking after neurological injury,^{19} although previous studies have not demonstrated simultaneous improvements in daily stepping and O_{2}-cost with physical interventions.

The current and previous data revealed markedly reduced daily stepping (2500 to 3500 steps/d) in individuals with chronic stroke as compared to sedentary older adults (5000 to 6000 steps/d), with significant contributions of reduced balance and metabolic capacity and efficiency.^{20} After specific exercise regimens, changes in walking speed, balance, and VO_{2} peak have been observed,^{21} although few studies have been able to detect changes in daily stepping in chronic stroke (see^{12} for subacute stroke). In the present study, daily stepping increased up to 4500 steps/d after LT, with significant improvements in O_{2}-cost. Despite this improvement, daily stepping after LT was still below average stepping in elderly individuals^{20} and below the threshold for “sedentary” individuals (ie, <5000 steps/d^{22}). Daily stepping below this threshold is thought to contribute to the progression of cardiovascular disease in the general population, which is exacerbated poststroke. Improvements in O_{2}-cost may contribute to improved daily stepping, but was still <25% to 40% worse than O_{2}-cost observed in elderly individuals without neurological injury (estimated from^{22}). Whether gait efficiency can improve further with continued LT and contribute to improved daily stepping is unclear and requires further investigation.

Limitations of the current study include lack of blinding of investigators and the small sample size. In addition, history or testing effects may have contributed to the study results, although the repeated measures crossover design was used to minimize these effects after clinical PT. However, we are uncertain whether subjects actually demonstrated a plateau in walking ability during the last 4 weeks of clinical PT, as significant improvements in clinical gait measures were observed. Such changes may be attributable to a testing effect, as O_{2}-cost measured during 12-minute walk test was slightly worse after PT. Nonetheless, the improvements observed after LT suggest that these subjects did not reach a plateau in locomotor function. Providing LT is feasible in the clinical setting, particularly when therapist assistance is not provided in subjects who are ambulatory poststroke (similar to the present protocol). Reasons why high intensity stepping practice is not provided more often are unclear, and the barriers to delivering this type of training should be identified. Further investigation is warranted to find solutions to facilitating more intensive LT during clinical PT, as the current results indicate that the minimal stepping practice may limit improvements in locomotor performance.

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**Disclosures**

None.

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