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INTRODUCTION

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ABSTRACT

INTRODUCTION

In last month’s issue (June 2007), we introduced the first of a four-issue special series of The American Journal of Physical Medicine & Rehabilitation, focused on innovative, physiologic treatments for stroke and traumatic brain injury.1 These disorders are leading causes of adult disability in the United States today, accounting for tremendous personal, social, and financial costs for survivors, caregivers, and society.

Brain injury survivors with spatial neglect (defined as a failure to report, respond, or orient to unilateral stimuli, associated with functional disability) face special challenges.2,3 They may receive no evaluation relevant to their visual-spatial disorder, or only a brief screening for cognitive dysfunction.4,5 They may receive little counseling or management in the short- or long-term stages of recovery—and even if we assume that only 10% of people with spatial neglect have chronic symptoms, more than 200,000 United States stroke survivors may still have neglect-related disability.6,7

In this issue, we are very pleased to present two articles on treatment innovation for spatial neglect. Choi and colleagues8 discuss the effect of optokinetic stimulation on an impairment measure in spatial neglect, suggesting that a simple computerized visual stimulus may reduce the manifestations of this disabling disorder. Although not standard care, this low-risk, inexpensive intervention deserves further study. Buxbaum and colleagues9 examine treatment of spatial neglect with amantadine, an NMDA antagonist with anticholinergic-like effects that is also used to treat viral infections and Parkinson disease. Their study does not support the wide use of this agent to improve neglect symptoms, but they report important information on methodology for successful neglect treatment trials.

In the August and September issues, we will present reports on pharmaceutical augmentation of rehabilitation and on refining existing physiologic treatment methods; we invite you to look for the continuation of this special series in those issues.

REFERENCES


Influence of Moving Background on Line Bisection Performance in the Normal Elderly Versus Patients with Hemispatial Neglect

ABSTRACT


Objective: Previous studies have shown that when healthy young participants bisect stationary lines on a moving background (MB) or optokinetic stimulation, they perceive the stationary line moving in the opposite direction of the MB (illusory motion [IM]), and they displace their bisection mark in the direction of the IM. This study attempted to learn whether IM also influences attentional biases of the healthy elderly and patients with hemispatial neglect.

Design: In experiment 1, healthy elderly participants and patients with neglect bisected lines in conditions where IM was absent or present. To better understand the MB dichotomy between the healthy elderly and neglect patients, in experiment 2, participants’ eye movements were recorded using an infrared eye tracker.

Results: In experiment 1, healthy elderly participants’ biases occurred in the opposite direction of MB when IM was present but in the same direction of MB when IM was absent. In contrast, neglect patients’ biases occurred in the same direction of MB regardless of conditions. Eye movements reflect the spatial direction of attention. In experiment 2, the healthy elderly participants were able to selectively attend to the line, whereas neglect patients were impaired in that they fixated on the line.

Conclusions: These results suggest that the healthy elderly can selectively fixate on a line, and with MB, they perceive the stationary line moving, resulting in a bisection bias in the direction of the IM. In contrast, when there is an MB, the patients with neglect are impaired in that they fixate on the line. Thus, they do not perceive IM; instead, they are primarily influenced by the MB.

Key Words: Attention, Line Bisection, Illusory Motion, Optokinetic Stimulation
Hemispatial neglect is the failure to report, orient to, or respond to novel or meaningful stimuli presented to the side opposite a brain lesion, when this failure cannot be attributed to either sensory or motor defects. Many different maneuvers have been reported to reduce the spatial bias associated with hemispatial neglect. The mechanisms underlying these therapeutic interventions have not been fully elucidated, but a subset of interventions seems to induce an illusion of stimulus or environmental movement in viewer-centered space. These include caloric stimulation of the ear, neck–muscle vibration, transcutaneous electrical nerve stimulation, and optokinetic stimulation (OKS) or moving background (MB).

One of the first treatments, cold-water irrigation of the left ear in patients with left hemispatial neglect, causes deviation of the eyeball to the left and rapid corrective eye movements toward right, presumably shifting the viewer’s center reference frame to the left, and resulting in temporary improvement of the signs associated with left neglect. Similarly, a leftward MB or OKS can also induce similar eye movements (slow leftward and rapid corrective rightward eye movements), suggesting that an MB may have the same beneficial effects on neglect as caloric stimulation. Neck–muscle vibration and transcutaneous electrical nerve stimulation also reduce the spatial bias associated with neglect; these treatments might work in a similar manner.

Several studies have suggested that movement of the background can influence the spatial bias associated with hemispatial neglect and can even induce attentional biases in healthy individuals. For example, when patients with neglect were asked to bisect stationary horizontal lines superimposed on an MB, the MB caused their attempts at line bisection to deviate, compared with no movement condition, in the direction of MB.

When people look at a stationary object on an MB, the stationary object might seem to move in the direction opposite the background motion, a phenomenon called illusory motion or induced motion (IM). Na et al. have demonstrated that in a condition where IM is absent, line-bisection errors (LBEs) of healthy participants occurred in the same direction of MB, replicating the results of previous studies; when the same participants bisection the lines in conditions where IM was present, LBEs occurred in a direction opposite that of the MB and in the direction of the IM.

Choi et al. have replicated and extended these results, showing in healthy young participants that the degree of IM correlates with the magnitude of line-bisection biases. Jeong et al. using an infrared eye tracker, attempted to learn the portion of a line to which healthy participants overtly attend when they are watching lines in real motion or with IM. These investigators found that with actual line movement, participants’ visual fixations centered on the leading part of the line. The participants’ attention skewed in the direction of IM, further supporting the postulate that IM can modulate the direction of healthy people’s attention.

Studies of patients with neglect performing line-bisection tests with MBs have revealed that these patients focus in the direction of the MB. If the MB had elicited IM, their attention would have been directed away from the MB. In these studies, however, the MB might not have been specifically designed for producing IM. Alternatively, the ability of these patients to attend to a stationary object on an MB might be altered; thus, they might perform differently on this task compared with healthy controls. The aim of this study was to investigate whether the influence of IM on the attentional biases of healthy people is different from the attentional biases of patients with hemispatial neglect, and, if so, what mechanisms might account for these differences.

**EXPERIMENT 1**

Experiment 1 examined the influence of MB on line-bisection performance in the healthy elderly vs. patients with hemispatial neglect.

**MATERIALS AND METHODS**

**Participants**

Participants consisted of 22 healthy volunteers and nine patients with left hemispatial neglect from right-hemisphere cerebral infarctions. The healthy participants were the spouses of neurology outpatients at Samsung Medical Center, Seoul, Korea and had no history of neurologic or psychiatric illnesses. Patients with stroke confined to the right hemisphere were consecutively recruited for a 6-mo period from the neurology inpatient service at Samsung Medical Center, Seoul, Korea and at Dongeui Medical Center, Busan, Korea. Patients who had decreased consciousness, severe cognitive deficits, inability to understand test instructions, or who refused to give consent were excluded from the study. All participants were right-handed as assessed by the Edinburgh handedness questionaire. The participants demonstrated binocular visual acuity above 20/30, either uncorrected or corrected. An informed consent, approved by the institutional review board of each hospital, was obtained from each participant.

Patients with stroke received a series of tests for neglect, including 1) solid-line bisection, 2) letter-line bisection, 3) star-line bisection, 4) Albert line cancellation, 5) star-cancellation task, and 6)
copying pictures (two daisy and the modified Ogden picture). The time interval from the onset of stroke to the neglect assessment ranged from 1 to 183 days (mean 54.7 ± 59.5). Details of administration and scoring methods have been described previously. The presence of hemispatial neglect was defined on the basis of norms established previously from 81 healthy participants. Briefly, each score from three bisection and two cancellation tasks was converted to a 10-point scale that ranged from −10 to +10, with the plus and minus values representing leftward and rightward bias. Seven points were given to the two figure-copying tasks. There are four objects in the modified Ogden scene and three objects within the two-daisy figure (i.e., left daisy, right daisy, and pot). For each object, we scored +1 for the left scene-based neglect, and +0.5 for the left object-centered neglect. Similarly, −1 was given for the right scene-based omissions and −0.5 for the right-sided, object-centered neglect. A final score was obtained by summing scores of the two drawings, yielding scores that ranged from −7 to +7. Thus, when summing the scores of these tests, the maximum possible score was +57, and the minimum possible score was −57. Therefore, left hemispatial neglect was defined as a total score that exceeds 2 SD of controls’ total score. According to these criteria, nine patients were diagnosed as having left hemispatial neglect. Controls and patients did not differ in sex (percentage of men: controls, 45%; patients, 78%; exact test, 2 = 0.132) or age (controls: 66.4 ± 5.3; patients: 63.7 ± 9.0; 2 = 1.06, 2 = 0.300).

Participants’ demographic data, the results of the neurological examinations, and the neglect assessments are presented in Table 1.

**Lesion Analysis**

All patients were imaged with either computed tomography (4/9) or magnetic resonance imaging (5/9). The lesions identified on axial scans were traced on the best-fitting template provided by Damasio and Damasio. A neurologist who was unaware of patients’ clinical information coded lesion site as involving the following areas: frontal, temporal, parietal, occipital lobes, thalamus, basal ganglia (caudate nucleus, putamen, globus pallidus), corpus callosum, internal capsule (anterior limb, posterior limb), and corona radiata. The localization of lesions is presented in Table 1, and the illustrations of these lesions are presented in Figure 1.

**Experimental Apparatus**

Stimuli were programmed by Microsoft Visual C++ (version 6.0) and Direct X (version 6.0) and were presented on a 19-inch (40 × 30 cm: visual angle 53.13 × 41.11 degrees) computer monitor. IM is elicited when a stationary object is surrounded by a large MB. To examine whether IM influences line-bisection performances of participants, we had participants bisect lines in the condition where IM is presumably present (large-background condition) or absent (small-background condition) (Fig. 1).

The large background, as illustrated in Figure 2A, consisted of alternating yellow and black vertical stripes that were 1.85 cm (2.65 degrees/sec) in width. A stationary horizontal line that was red and 12.5 × 0.2 cm (18.81 × 0.29 degrees) in size was centered on this background. The background moved leftward or rightward at speeds of 1.26 cm/sec (1.81 degrees/sec) (S1), 11.07 cm/sec (15.76 degrees/sec) (S2), or 20.87 cm/sec (29.25 degrees/sec) (S3). A previous study has shown that the background moving at these speeds induces IM of the stationary line centered in the background.

In addition to these six conditions (three different speeds in two directions), there was a control condition that was identical to the moving conditions, except that the vertical stripes were absent and were replaced by a gray background. Therefore, participants performed line bisections in a total of seven conditions.

When the MB is smaller than the stationary object, IM does not occur. Thus, in the second background condition (small-background condition), the width of the background was made smaller than that of the horizontal line. As presented in Figure 1B, the size of the MB was reduced to 32.5 × 24.1 cm (44.22 × 33.53 degrees)—80% of the size used in the large-background condition—but the width of the vertical stripes was unchanged. The horizontal line was increased in length to 38.5 cm (51.40 degrees)—approximately three times as long as the line used in the large-background condition, but with same thickness. MB speed conditions were the same as in the large-background condition. There was also a control condition in which the background was replaced by a gray background. Therefore, participants performed line bisections in a total of seven conditions (three speeds in two directions, and a control condition).

The horizontal line on the computer screen was presented at the level of the participants’ eyes, with a viewing distance of 40 cm, and the midline of the screen was aligned with the midsagittal plane of each subject’s head and body. Most Korean elderly participants are not accustomed to using a computer mouse, so participants bisected the line on the computer screen with a pen held in their right hand, and then the examiner clicked on the mark after aligning the cursor with the mark. Clicking the computer mouse was immediately followed by the next trial, and LBEs were automatically computed. Negative values represent leftward
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<th>Subject No.</th>
<th>Days since Onset</th>
<th>Neurological Examination</th>
<th>Solid-Line Bisection, mm&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Star-Line Bisection, mm&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Letter-Line Bisection, mm&lt;sup&gt;a&lt;/sup&gt;</th>
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<td>3. F/51</td>
<td>183</td>
<td>M, S</td>
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<td>23.7</td>
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<td>24/26</td>
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<td>+</td>
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<td>4. F/73</td>
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<td>0/15</td>
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<td>F, P, T, CR, border zone</td>
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<td>M</td>
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<td>M</td>
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<td>12.7</td>
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<td>–</td>
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<td>–</td>
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<td>8. M/65</td>
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<td>6</td>
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<td>22</td>
<td>M, S, V</td>
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<td>18/15</td>
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<td>+</td>
<td>+</td>
<td>F, T, O, Th, splenium of CC</td>
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<sup>a</sup> Lines were 242 mm long. Negative values indicate leftward errors from the true midpoint, and positive values rightward errors.

<sup>b</sup> The maximum possible score is 18/18 for line cancellation and 27/27 for star cancellation. Two daisy and modified Ogden were rated as presence (+) or absence (−) of left neglect.
deviation from the true midpoint, and positive values indicate rightward errors.

**Experimental Line-Bisection Task**

The mean interval between the neglect tests and the experimental task was $2.6 \pm 5.8$ days. In both the large- and the small-background conditions, participants performed four bisection trials in each of the seven conditions (three different background speeds, two different directions, one gray background). The total of 28 trials was divided into three blocks. There was a 2-min break between the second and third blocks. The first block consisted of four control trials. The second and the third blocks each consisted of 12 trials of the three leftward or three rightward movement conditions (S1, S2, and S3). The first block always preceded the second and third blocks, but the second and the third blocks alternated in sequence so that half of the participants performed the leftward MB block first, and the other

**FIGURE 1** An illustration for lesion sites in patients with neglect.

**FIGURE 2** Stimuli used in experiment 1. A, Large-background condition. B, Small-background condition.
half performed the rightward MB block first. In the second and the third blocks, the sequence of 12 trials was randomized. There were four practice trials before the experiment. Half the participants performed the large-background condition first, and the other half of the participants performed the small-background condition first. It took about 15 mins for each subject to complete experiment 1.

RESULTS

Line-Bisection Performances of the Healthy Elderly

Large-Background Condition

In the large-background condition, the mean LBE in the control condition deviated slightly to the left (−0.88 ± 1.68 mm, −1.40%), which differed significantly from the veridical midpoint (t = −2.45, P = 0.023). In the large-MB condition, the mean LBE (1.20 ± 2.26 mm, 1.92%) in the leftward MB conditions (all speed conditions averaged) deviated significantly to the right from that of the control condition (t = 3.18, P = 0.004). The mean LBE (−1.13 ± 3.76 mm, −1.80%) in the rightward MB conditions did not deviate significantly from the control condition (t = −0.36, P = 0.723).

With regard to the specific speed conditions, as presented in Figure 3A, mean LBEs in each leftward moving speed condition were as follows: −0.65 ± 1.88 mm (1.05%) for S1, 1.63 ± 2.63 mm (2.61%) for S2, and 1.31 ± 3.28 mm (2.09%) for S3. The LBEs for the different rightward MB speed conditions were as follows: −1.08 ± 3.93 mm (−1.73%) for S1, −1.68 ± 3.21 mm (−2.69%) for S2, and −0.62 ± 4.88 mm (−0.98%) for S3. To test whether these LBEs differed from those of the control conditions, t tests with Bonferroni correction were performed. The results show that the LBEs at S1, S2, and S3 background speeds with the leftward MB condition deviated significantly to the right with respect to the control condition (S1: t = 2.83, P = 0.030; S2: t = 3.35, P = 0.009; S3: t = 2.63, P = 0.047), but the LBEs at S1, S2, and S3 background speeds with the rightward MB did not differ significantly from the control condition (S1: t = −0.26, P > 0.999; S2: t = −1.37, P = 0.556; S3: t = −0.30, P > 0.999).

For both the rightward and leftward conditions, the MB speed had no significant effect on line-bisection performance (leftward: F = 1.84, P = 0.171; rightward: F = 1.80, P = 0.178).

Small-Background Condition

In the small-background condition, the mean LBE for the control condition was 0.68 ± 4.97 mm (0.35%), which did not differ significantly from the
true midpoint \((t = 0.65, P = 0.526)\). In the small-MB condition, LBEs deviated to the same direction of the MB (Fig. 3A, right column). That is, the mean LBE \((-11.81 \pm 11.44 \text{ mm}, -6.13\%)\) in the leftward MB conditions (all speed conditions averaged) deviated significantly to the left from that of the control condition \((t = -4.64, P = 0.000)\). Likewise, the mean LBE \((17.33 \pm 14.76 \text{ mm}, 9.00\%)\) in the rightward MB conditions deviated significantly to the right with respect to the control condition \((t = 5.45, P = 0.000)\). The mean LBEs in each speed condition were as follows: \(-5.73 \pm 5.61 \text{ mm} (-2.98\%)\) for leftward S1, \(-12.80 \pm 13.60 \text{ mm} (-6.65\%)\) for leftward S2, and \(-16.89 \pm 17.37 \text{ mm} (-8.77\%)\) for leftward S3; and \(10.98 \pm 9.27 \text{ mm} (5.71\%)\) for rightward S1, \(19.04 \pm 16.92 \text{ mm} (9.89\%)\) for rightward S2, and \(21.96 \pm 20.36 \text{ mm} (11.41\%)\) for rightward S3. The results of \(t\) tests with Bonferroni correction show that LBEs of all MB conditions differed significantly from those of the control condition, and all were in the direction of the MB with respect to the control condition (leftward, S1: \(t = -4.60, P = 0.000; S2: t = -4.28, P = 0.001; S3: t = -4.46, P = 0.001\); rightward, S1: \(t = 5.17, P = 0.000; S2: t = 5.20, P = 0.000; S3: t = 5.07, P = 0.000\)). When leftward and rightward conditions were analyzed separately to find whether the speed affected LBEs, the speed effect was significant for both leftward and rightward MB conditions (leftward: \(t = -8.08, P = 0.016; S2\) and S3: \(t = 8.00, P = 0.002)\). Rightward MB condition, as in the large-background condition, LBEs occurred in the same direction of the MB. That is, the mean LBE of the leftward condition \((-8.08 \pm 60.22 \text{ mm}, -4.20\%)\) deviated significantly leftward from that of the control condition \((t = -3.90, P = 0.005)\). Likewise, the mean LBE of the rightward condition \((64.06 \pm 47.40 \text{ mm}, 33.28\%)\) deviated significantly to the right with respect to the control condition \((t = 3.58, P = 0.005)\). Mean LBEs in each speed condition were as follows: \(7.55 \pm 55.13 \text{ mm} (3.92\%)\) for S1, \(-8.38 \pm 61.01 \text{ mm} (-4.35\%)\) for S2, and \(-23.42 \pm 69.72 \text{ mm} (-12.17\%)\) for S3 in the leftward conditions; and \(49.46 \pm 50.71 \text{ mm} (25.69\%)\) for S1, \(72.83 \pm 48.80 \text{ mm} (37.83\%)\) for S2, and \(69.91 \pm 47.20 \text{ mm} (36.32\%)\) for S3 in the rightward conditions. The results of \(t\) tests with Bonferroni correction showed that the leftward S2 and S3 conditions \((S2: t = -4.44, P = 0.006; S3: t = -3.53, P = 0.023)\) and the rightward S2 and S3 conditions \((S2: t = 3.80, P = 0.016; S3: t = 4.19, P = 0.009)\) differed significantly from the LBEs of the control condition. In the remaining conditions, deviations did not differ from those of the control condition. When the leftward and rightward conditions were analyzed separately to find whether speed affected LBEs, the speed effect was significant in the leftward condition \((F = 5.81, P = 0.013)\); LBEs increased significantly from S1 to S2 and from S2 to S3.

**Small-Background Condition**

In the small-background condition, the mean LBE of the control condition was \(27.59 \pm 49.40 \text{ mm} (14.33\%)\), which was not significantly different from the vertical midpoint \((t = 1.68, P = 0.132)\). In the MB condition, as in the large-background condition, LBEs occurred in the same direction of the MB. That is, the mean LBE of the leftward condition \((-8.08 \pm 60.22 \text{ mm}, -4.20\%)\) deviated significantly leftward from that of the control condition \((t = -3.90, P = 0.005)\). Likewise, the mean LBE of the rightward condition \((64.06 \pm 47.40 \text{ mm}, 33.28\%)\) deviated significantly to the right with respect to the control condition \((t = 3.58, P = 0.005)\). Mean LBEs in each speed condition were as follows: \(7.55 \pm 55.13 \text{ mm} (3.92\%)\) for S1, \(-8.38 \pm 61.01 \text{ mm} (-4.35\%)\) for S2, and \(-23.42 \pm 69.72 \text{ mm} (-12.17\%)\) for S3 in the leftward conditions; and \(49.46 \pm 50.71 \text{ mm} (25.69\%)\) for S1, \(72.83 \pm 48.80 \text{ mm} (37.83\%)\) for S2, and \(69.91 \pm 47.20 \text{ mm} (36.32\%)\) for S3 in the rightward conditions. The results of \(t\) tests with Bonferroni correction showed that the leftward S2 and S3 conditions \((S2: t = -4.44, P = 0.006; S3: t = -3.53, P = 0.023)\) and the rightward S2 and S3 conditions \((S2: t = 3.80, P = 0.016; S3: t = 4.19, P = 0.009)\) differed significantly from the LBEs of the control condition. In the remaining conditions, deviations did not differ from those of the control condition. When the leftward and rightward conditions were analyzed separately to find whether speed affected LBEs, the speed effect was significant in the leftward condition \((F = 5.81, P = 0.013)\); LBEs increased significantly from S1 to S2 and from S2 to S3.

**Line-Bisection Performances of Patients with Hemispatial Neglect**

**Large-Background Condition**

In the large-background condition, the mean LBE of the control condition was \(7.12 \pm 8.00 \text{ mm} (11.4\%)\), which deviated significantly to the right from the vertical midpoint \((t = 2.67, P = 0.028)\). In the MB condition, the mean LBE of the leftward condition (all speed conditions averaged) was \(-4.96 \pm 18.58 \text{ mm} (-7.94\%)\), which deviated significantly to the left with respect to the control condition \((t = -2.71, P = 0.027)\). Likewise, the mean LBE of the rightward condition \((24.79 \pm 15.41 \text{ mm}, 39.66\%)\) deviated significantly to the right with respect to the control condition \((t = 4.38, P = 0.002)\). As presented in Figure 3B, mean LBEs in each speed condition were as follows: \(0.16 \pm 18.68 \text{ mm} (0.26\%)\) for S1, \(-5.80 \pm 19.76 \text{ mm} (-9.27\%)\) for S2, and \(-9.25 \pm 19.29 \text{ mm} (-14.81\%)\) for S3 in the leftward conditions; and \(-19.48 \pm 14.89 \text{ mm} (-31.17\%)\) for S1, \(27.11 \pm 15.97 \text{ mm} (43.37\%)\) for S2, and \(27.78 \pm 18.62 \text{ mm} (44.44\%)\) for S3 in the rightward conditions. The results of \(t\) tests with Bonferroni correction showed that LBEs at rightward S1, S2, and S3 deviated significantly rightward from those of the control condition \((S1: t = 3.79, P = 0.016; S2: t = 4.57, P = 0.005; S3: t = 3.68, P = 0.019)\), but the LBEs at leftward S1, S2, and S3 did not differ significantly from those of the control condition, except for S3 \((S1: t = -1.66, P = 0.406; S2: t = -2.71, P = 0.080; S3: t = -3.11, P = 0.043)\). When the leftward and rightward conditions were analyzed separately to find whether the speed affected LBEs, the speed effect was significant in the leftward condition \((F = 5.41, P = 0.016)\); LBEs increased significantly from S1 to S2 and from S2 to S3 \((F = 6.54, P = 0.034)\). In the rightward condition, the speed effect was marginally significant \((F = 3.45, P = 0.057)\); LBEs tended to increase from S1 to S2 and from S2 to S3 \((F = 3.76, P = 0.088)\) (Fig. 3B).
S3 ($F = 8.64, P = 0.019$). In the rightward condition, the speed effect also was significant ($F = 6.63, P = 0.008$); LBEs increased from S1 to S2 and decreased slightly from S2 to S3 ($F = 7.69, P = 0.024$) (Fig. 3B).

In summary, patients with neglect showed that LBEs deviated in the same direction as the background in both the large- and small-MB conditions.

### Accuracy of Line Bisection in Patients with Hemispatial Neglect

So far, we have investigated the directions in which patients' bisection biases occurred according to the size and direction of the MB. However, from the treatment perspective, the accuracy of line bisection rather than the direction of bias should be considered. Thus, with the absolute value of LBEs, we analyzed how close the LBEs were to the vertical midpoint. The data from the three different speed conditions were averaged.

#### Large-Background Condition

The mean absolute LBEs of the control, leftward, and rightward conditions were $7.78 \pm 7.28$, $12.34 \pm 14.20$, and $24.79 \pm 15.41$ mm, respectively. The absolute LBEs for the control condition differed significantly from zero ($t = 3.21, P = 0.013$). The absolute LBEs of the leftward MB did not differ from those of the control condition ($t = 1.01, P = 0.340$), whereas the absolute LBEs of the rightward MB were greater than those of the control condition ($t = 4.51, P = 0.002$). These results suggest that the leftward MB did not improve the accuracy of line bisection, but the rightward MB aggravated the accuracy of line bisection.

#### Small-Background Condition

The mean absolute LBEs of the control, leftward, and rightward conditions were $29.31 \pm 48.28$, $38.16 \pm 45.41$, and $64.06 \pm 47.40$ mm, respectively. The absolute LBEs of the control condition did not differ from zero ($t = 1.82, P = 0.106$). As in the results of the large-background condition, the absolute LBEs of the leftward MB did not differ from those of the control condition ($t = 0.78, P = 0.460$), whereas the absolute LBEs of the rightward MB were greater than those of the control condition ($t = 3.83, P = 0.005$).

### DISCUSSION

In the healthy elderly, large-background conditions induced biases in the direction opposite the background motion, suggesting that MBs induced IM in these participants. These results replicate the results of Na et al.¹⁵ and Choi et al.¹⁶ involving young participants. To provide further support for the postulates that a large background induces IM and that IM modulates healthy participants’ attention, we requested that these same elderly participants bisect lines in the small-MB condition where IM was absent; as expected, in this MB condition, the healthy elderly showed biases in the same direction of MB.

In the large-background condition, although the mean biases of the healthy elderly occurred in the opposite direction of the MB, it was only on the leftward MB condition where the bisection biases significantly differed from the biases in the control conditions. This asymmetry might suggest that the leftward MBs elicit greater IM than the rightward MBs. This account accords with the results of Jeong et al.’s¹⁷ study, which investigated healthy participants’ overt attention using an infrared eye tracker while participants were watching a stationary line on an MB. This study also has revealed that overt attention was distributed in the opposite direction of MB, and more so with leftward than with rightward MB. The underlying cause of this asymmetry is unknown, but it might be related to a right-hemispheric attentional dominance such that a leftward MB has a greater influence than a rightward MB, because with leftward movement, the MB is more strongly attended to than with rightward MB. Against this hypothesis is the observation that in the small-MB condition, where subjects deviated in the direction of the MB, normal subjects did not deviate more to the left than to the right. Alternatively, this asymmetry might be related to an asymmetry of IM such that IM is more easily developed going from left to right than vice versa, and this asymmetry might be related to the left-to-right scanning habits (i.e., reading habit) of participants.²²

In contrast to controls, patients with neglect showed biases in the same direction of background motion regardless of whether the background was larger or smaller than the stimulus. These results suggest either that neglect patients do not develop IM in the large-background condition, or that these patients are not influenced by IM. Patients with neglect might be unable to perceive IM because the brain regions that mediate motion perception (e.g., MT area) have been injured. However, most patients with neglect in our study were not injured in MT. Furthermore, functional magnetic resonance imaging studies have shown that brain regions that mediate real motion and induced motion are the same.²¹ In addition, the fact that neglect patients’ attention was strongly affected by the background motion also argues against this hypothesis. IM effect is maximized when the participants selectively foveate the line. Thus, the differential effect of MB on healthy participants as opposed to neglect patients might have been asso-
associated with the fact that neglect patients have a limited attention capacity and a decreased ability to selectively attend. Unlike healthy participants, who may be able to selectively attend the line, the patients with neglect might allocate most of their attention to the MB.

It may be argued that the difference between the large- and small-background conditions might have been related to the difference in line length. Previous studies have shown that in normal individuals or in patients with neglect, LBEs on longer lines (about 5–27 cm) can occur in the opposite direction from those of shorter lines (0.5–5 cm)—a paradoxical phenomenon called the crossover effect. However, the line lengths (12.5 or 38.5 cm) used in our study were within the range of longer lines from previous studies. Thus, it is less likely that the difference in line length explains the difference between the large- and small-background conditions.

**EXPERIMENT 2**

Experiment 2 examined eye-movement patterns during a line-bisection task in the healthy elderly vs. patients with neglect.

To help better understand the mechanisms that might account for the discrepancy between healthy participants and neglect patients, we performed experiment 2, in which overt eye movement of the participants was recorded using an infrared eye tracker. In general, people move their eyes in the direction to which they are attending. If patients with neglect cannot sustain attention and fixate on the stimulus lines, then, compared with healthy participants, their gaze will be more frequently directed to the background rather than the stationary line.

**MATERIALS AND METHODS**

**Participants**

Participants consisted of three (two men and one woman; mean age, 61.3 ± 11.2 yrs) healthy elderly participants and three patients (two men and one woman; mean age, 72.3 ± 8.7 yrs) with left hemispatial neglect from right-hemispheric infarctions. One of the patients participated in experiment 2 as well as experiment 1 (patient 8 in experiment 1, Table 1). Healthy participants and patients did not differ in age (Mann-Whitney test, \( P = 0.275 \)). The healthy participants were spouses of neurology outpatients at Samsung Medical Center, Seoul, Korea and had no history of neurologic and psychiatric illness. The three patients with left neglect were consecutively recruited during a 3-mo period from neurology inpatients at Samsung Medical Center, after excluding patients who had decreased levels of consciousness or severe cognitive deficits, who could not cooperate for the eye recording, or who refused to give consent. The participants demonstrated binocular visual acuity above 20/30, either uncorrected or corrected. All participants were right-handed and provided the informed consent approved by the institutional review board.

The patients underwent the same neglect tests described in experiment 1. The time interval from the onset of stroke to the neglect assessment ranged from 1 to 26 days (mean 11.0 ± 13.2). Demographics and results of neurologic and neglect assessment are presented in Table 1.

**Apparatus for Line Bisection**

Stimuli used in experiment 2 were the same as the stimuli used in experiment 1, but only the large background moving at 5.00 cm/sec (5.72 degrees/sec) was used. The stimuli were presented on a 17-inch (34 × 27 cm, visual angle 37.56 × 30.43 degrees) computer monitor with a viewing distance of 50 cm. The actual midpoint of each line was aligned with the monitor’s center and the midsagittal plane of the viewer’s body.

**Line-Bisection Procedure and Eye-Movement Recording**

As in experiment 1, there were three conditions: control, leftward, and rightward MB. One trial was conducted for each condition. As illustrated in Figure 4, the control trial preceded the MB trials, and the sequence of rightward and left-
ward trials was counterbalanced. To determine the portion of the line that each participant fixated, before the bisection trials, calibrations were conducted (precalibration); after the bisection trials, the calibration procedure was repeated (postcalibration). The calibration point was a red circle, 6 mm in diameter, with a central, 2-mm-diameter hole that was presented at four locations on the monitor screen: 5.35 cm rightward and leftward, as well as 5.75 cm above and below the geographic center of the screen. These calibration points were presented one at a time for 5 secs at each location in the following order: rightward, leftward, above, and below (Fig. 4).

For eye-movement recording, each subject was seated on an adjustable chair with his or her head and chin stabilized using a frame with a chin rest and forehead brace. The pre- and postcalibrations (20 secs per calibration) and the three bisection trials (15 secs per trial) were performed as a block. There was a 10-sec pause between trials or between the trial and the calibration. Thus, the entire block took about 125 secs. The participants were instructed to avoid head movements. Before and after each bisection trial, the participants were asked to close their eyes while the stimulus was switched to the next stimulus (about 10 secs). In each bisection trial, the participants were asked to find the horizontal line on opening their eyes, to estimate the midpoint of this line, and then fixate on the subjective midpoint until asked to stop (close their eyes). The time interval from eye opening to closing in each trial was 15 secs. During this interval, an infrared eye tracker (iViewX Hi-Speed system, Sensomotoric Instruments, Berlin, Germany) tracked the horizontal and vertical position of the subject’s left eye with a spatial resolution of 0.025 degrees and a temporal resolution of 240 Hz.

RESULTS

We performed pre- and postcalibration to assure that the eye-tracker settings remained unchanged during the bisection trials. The differences between pre- and postcalibrations for the control participants were 1.18 degrees (control 1), 2.66 degrees (control 2), and 4.34 degrees (control 3), and the mean was 2.73 degrees. The differences for the patients were 4.63 degrees (patient 1), 14.08 degrees (patient 2), and 1.90 degrees (patient 3), and their mean was 5.72 degrees. Because this pre–post test change in calibration exceeded our operational standard of 1.5 degrees, we cannot precisely know the parts of the stimulus to which participants were looking. However, as demonstrated in Figure 5 and Table 2, the ranges of vertical eye positions were greater for the patients than for the controls, suggesting that the patients were looking at the background more frequently and for a longer time than were the healthy controls, and, therefore, the patients also viewed the stimulus line less often than did the healthy controls. To learn the variation of vertical position as a function of time, we analyzed the range of vertical position during the first the first 7.5 secs and the next 7.5 secs. The results show that patients had greater SDs and ranges than controls in both the first and second 7.5 secs (Table 2).

GENERAL DISCUSSION

The results of experiment 2 suggest that compared with the patients, healthy controls are better able to selectively fixate on the stationary line. The inability of the patients with neglect to maintain fixation on the line might account for these patients’ inability to perceive the IM. According to Jeong et al.’s study, participants’ attention is biased to the leading part of moving objects regardless of whether the movement is real or induced. Thus, controls who were able to fixate on the line had the illusion of the line moving in the direction opposite the MB, and their bisection biases occurred toward the induced motion of the line, away from the direction of the MB. In contrast to the control participants, the biases of the patients with neglect were primarily influenced by the real background movement.

<table>
<thead>
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<th>Table 2</th>
<th>Mean values of vertical eye-movement ranges during line-bisection performances (experiment 2)</th>
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<td>Group</td>
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<td>Controls</td>
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FIGURE 5  Traces of eye movements during bisection trials were recorded using an infrared eye tracker and were superimposed on the stimulus. A, Performance of controls (C1, C2, and C3). B, Performance of patients with neglect (P1, P2, and P3).
Why the patients with neglect were unable to maintain fixation on the line is not entirely known. The observation that these patients had trouble fixing the line even when there was no background movement would suggest that it was not the background movement that distracted them. Patients with neglect have been shown to have reduced arousal, and they might even be inattentive to stimuli on the side ipsilateral to their lesion. People who have reduced arousal–attention are less vigilant, and their inability to focus their attention on the line might be a manifestation of this arousal–attentional disorder.

OKS or MB may be less invasive compared with other vestibular or IM-related methods. It is also easy to administer and cost-effective. However, the OKS can be administered only via visual modality; thus, it can be effective only when patients properly fixate on the target or background stimulation. Our results in experiment 2 demonstrate that patients with neglect might have difficulty properly fixating on the target or even the MB (e.g., fixations occurred far beyond the boundary of the MB in patient 2 in Fig. 5). Furthermore, the results of experiment 1 show that in neglect patients, leftward OKS did not improve the accuracy of line bisection and the rightward OKS aggravated it, although OKS did affect the direction of biases. Thus, OKS is a less promising rehabilitation intervention than other methods.

Experiment 2 has several limitations. The presence of vertical neglect was not investigated in patients with neglect. Thus, the possibility that greater variability in ranges of vertical eye positions in patients than in controls was confounded by the fact that vertical neglect cannot be completely excluded. Second, the eye-tracker settings did not remain constant during bisection trials, which failed to precisely demonstrate the parts of the stimulus to which participants were looking. Finally, the small number of participants, and our having recruited only patients with severe neglect, may limit the generalization of data.

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REFERENCES

Amantadine Treatment of Hemispatial Neglect
A Double-Blind, Placebo-Controlled Study

ABSTRACT

Objective: The resemblance of some aspects of the hemispatial ne-glect syndrome (hypokinesia, decreased arousal) to aspects of Parkinso-nian syndromes, and the success of amantadine in treating disorders of attention, prompted a placebo-controlled, double-blind trial of amantadine, an inhibitor of the N-methyl d-aspartate (NMDA) glutamate receptor that modulates dopamine transmission, in four patients with chronic hemispatial neglect.

Design: Patients received placebo or 100 mg of amantadine twice a day in an ABA design. Dependent measures of drug effect included an extensive battery of tests assessing arousal, hemiattention, hemihypokinesia, personal neglect, disability, anosognosia, family burden, and naturalistic action.

Results: There was no evidence of increased adverse effects with the treatment drug compared with placebo. Of the 17 measures used to assess treatment response in the four patients (68 measures total), linear regressions revealed significant positive treatment effects on very few (four) measures (uncorrected for multiple comparisons), and scattered negative responses to treatment were evident on three measures. The vast majority of measures showed no change in response to treatment.

Conclusions: Possible reasons for failure of treatment effects in the present study are discussed. Additional study will be required to determine whether there are neglect patients who may benefit from amantadine.

Key Words: Amantadine, Neglect Treatment, Pharmacology of Hemispatial Neglect, Hemispatial Neglect Treatment, NMDA, Glutamate Antagonists, Parkinsonian Syndromes
Hemispatial neglect is a complex syndrome characterized by failure to report, orient toward, or respond to stimuli on the contralesional side of space that cannot be attributed to primary motor or sensory dysfunction. Lateralized deficits in spatial attention and motor intention/action, hypoarousal, and unawareness of deficit are also commonly encountered. Neglect is a relatively frequent consequence of lesions to the right hemisphere, occurring in approximately 50% of patients who have suffered right-hemisphere cerebral vascular accident, and persisting chronically in at least mild form in approximately 75% of patients. The disorder may occur subsequent to lesions to the inferior parietal lobe, frontal lobe, thalamus, basal ganglia (striatum), and/or superior temporal gyrus. Neglect has a significant impact on rehabilitation, disability, and family burden beyond that predicted by lesion size.

There are several subtypes of neglect that may occur together or, much more rarely, in isolation. For example, neglect may primarily affect the left of the body (personal neglect), the left of near or far space (peripersonal or extra-personal neglect), movements in and toward the left side of space (motor intentional neglect), or detection of targets on the left, irrespective of the type of response required to indicate detection (sensory neglect). One of the most robust observations about neglect patients is that they exhibit hypokinesia (decreased motor responsiveness), even for movements in ipsilesional space, along with more pronounced slowing or reduction in movements of the head, eyes, limbs, and torso in a contralesional direction (directional hypometria or hypokinesia). These disorders of movement raise the possibility that dopamine (DA) depletion may play a role in the disorder. In fact, there is evidence that dopaminergic receptors may be asymmetrically lateralized to the right hemisphere. This suggests that prominent aspects of the neglect syndrome might result from damage to predominantly dopaminergic right-hemisphere subcortical and cortical structures that mediate both general arousal and attention to the contralesional hemispace.

There are several lines of evidence that decreased levels of DA may be implicated in neglect. Data from studies with animals indicate that ascending DA systems projecting to the frontal cortex, neostriatum, and cingulate gyrus are involved in motor intention, sensory orienting, and arousal. DA levels also correlate with neglect severity in rats. Neglect can be induced by injections of the dopaminergic neurotoxin 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine into the caudate nucleus of the monkey. The DA-receptor agonist apomorphine reduces neglect in lesioned animals, and the DA blocker spiroperidol reverses this treatment effect.

These data suggest that DA agonists might effectively treat neglect in humans. Results supporting this possibility were obtained by Fleet et al., who have shown that 15 mg/day of the DA agonist bromocriptine was effective in reducing neglect in two patients with large right-hemisphere strokes. For one subject, neglect worsened on discontinuation of the medication. Similarly, Geminiani et al. have shown positive effects of treatment with 2 mg of apomorphine in four neglect patients. Methylphenidate (Ritalin), a medication that enhances the activity of several monoamine neurotransmitters, including DA, and that has been shown to improve the speed of mental processing in patients with traumatic brain injury and attention-deficit disorder, also has been used as a treatment for neglect. Hurford et al. assessed the efficacy of 20 mg/day of methylphenidate in a patient with chronic neglect caused by middle cerebral artery stroke. Methylphenidate was as effective as 30 mg/day of bromocriptine, and improvements were maintained after the medications were discontinued. Finally, Mukand et al. have reported that carbidopa/levodopa in doses of 25/100 mg, three times daily, improved neglect in three of four patients with left neglect secondary to right-hemisphere stroke.

However, less encouraging results have also been obtained in a number of studies. One recent study examined the performance of seven right-hemisphere cerebral vascular accident patients who exhibited asymmetric target-detection performance on a computerized target-search paradigm; many of the patients exhibited decreased exploration and prolonged reaction times in the contralesional hemispace with 2.5 mg of bromocriptine. This finding is difficult to interpret, because bromocriptine may inhibit DA receptors at low doses. However, it is of note that all of the poor responders had lesions that included the striatum, and one patient, whose response was positive, did not have striatal damage. Barrett et al. have reported a patient with motor neglect caused by right middle cerebral artery stroke, whose performance on a line-bisection task declined on 20 mg/day of bromocriptine. The investigators suggest that bromocriptine may have differentially activated the intact dopaminergic system of the left hemisphere, with relatively less activation of the damaged dopaminergic system of the right hemisphere, thereby exacerbating the ipsilesional bias. They also suggest that the presence of right subcortical involvement may have prevented DA transmission to the right parietal spatiomotor system.

In this study, we assessed the efficacy of amantadine, a glutamate antagonist having modulatory
effects on DA transmission. Selection of this medication was guided in part by theories of the pathophysiology of Parkinson disease (PD) and in part by evidence that amantadine has been successful in treating disorders of attention in nonfocal pathologies such as traumatic brain injury and multiple sclerosis.

PD may result from loss of DA neurons in the substantia nigra, thus reducing DA levels in the putamen. There are two populations of DA receptors in the putamen, both of which are inhibitory. The first are D1 receptors, on which DA has an excitatory effect, and the second are D2 receptors, on which DA has an inhibitory effect. The opposite effects of DA depletion on the two putamen subpopulations are important in the pathophysiology of PD. D1 receptors become hypoactive and, in turn, provide less inhibition of the globus pallidus (GP). D2 receptors are overactive; consequently, they induce net excitation of the GP. The GP excessively inhibits a portion of the thalamus, reducing excitatory output to the supplementary motor area. This loss of excitatory output to the cortex seems to underlie the hypokinetic deficits of PD.

In at least some patients with neglect, striatal damage that mitigates the positive effects of DA therapy may result from mechanisms that are similar to those that occur in PD. A possible treatment strategy involves targeting the subthalamic nucleus, which receives excitatory glutamatergic projections from the motor and premotor cortex and, in turn, has excitatory glutamatergic projections to the GP. To effect a reduction in GP activity (and, hence, a reduction of thalamic and cortical inhibition), a possible pharmacologic intervention could inhibit excitatory effects of the subthalamic nucleus on the GP or of the cortex on the subthalamic nucleus. Amantadine is a low-potency glutamate antagonist thought to counteract these excitatory effects. Glutamate antagonists such as amantadine have antiakinetic effects in animal models of PD, and amantadine has long been used as an antiparkinsonian in humans (see, for example, Thomas et al.).

It is also possible that amantadine may have general or “nonspecific” beneficial effects on attention and/or cognition. The medication has been used as a treatment of fatigue in patients with multiple sclerosis, although the effects have not been robust (e.g., reference 32). Similarly, it has been used in the treatment of traumatic brain injury, albeit with mixed results; Meythaler et al. have reported significant recovery in a double-blind crossover design (but see Giacino et al. for a critique), whereas Schneider et al. have reported no benefit from amantadine in a traumatic brain injury rehabilitation setting. It remains possible that amantadine might prove to have beneficial effects on arousal and attention in the neglect syndrome.

To assess the efficacy of amantadine in treating neglect, we performed a double-blind, placebo-controlled exploratory study in which patients were administered a placebo (A1), then amantadine (B), then another placebo (A2). An important aspect of our procedure was a careful attempt to establish a stable baseline of performance during the A1 phase, to ascertain that any changes during the B phase were not just random variability. Additionally, because neglect is a multifactorial syndrome, we used a thorough battery of neglect tests designed to permit assessment of possible differential treatment effects on motor, sensory, personal, and peripersonal neglect. In addition to using these various tasks to assess treatment-related changes, we also were interested in assessing how these tests performed over repeated administrations. Other goals of the trial were to establish the safety of the medication in this population of patients, and the feasibility of performing additional studies if appropriate.

METHODS

Subjects

Subjects were recruited from a pool of seven MossRehab and Bryn Mawr Rehabilitation Hospital chronic right-hemisphere stroke patients who had been identified in a previous study as having at least moderate neglect, and who expressed interest in participation. Patients were considered eligible for the present study if they had sustained a right-hemisphere hemorrhagic, embolic, or thrombotic cerebrovascular accident (right-hemisphere cerebral vascular accident) 6–36 mos previously. Patients with history of previous head injury, left-hemispheric stroke, or other neurologic disorder were excluded, as were those suffering from DSM-IV axis I disorder (e.g., major depression, psychosis, dementia) at the time of the study. Pregnant women were excluded. Inclusion was also based on three behavioral criteria gleaned from review of the medical chart and prior testing data: a) language comprehension adequate to understand task instructions; b) motor capacity, hearing, and visual function sufficient to perform the testing protocol; c) arousal and behavioral control adequate for a 60-min testing session. All subjects gave informed consent to participate in the study in accordance with the guidelines of the institutional review board of Albert Einstein Healthcare Network (MossRehab) and Lankenau Health System (Bryn Mawr Rehabilitation Hospital).

Preliminary testing was conducted to confirm that neglect was indeed still present. Neglect was defined by performance below cutoff scores on at
least one of five standard neglect tests—the bell test\textsuperscript{37} and four subtests of the Behavioral Inattention Test (BIT)\textsuperscript{38}: 1) letter cancellation, 2) picture scanning, 3) menu reading, and 4) line bisection (see Test Protocol section, and Buxbaum et al.\textsuperscript{2}, for test descriptions and scoring procedures). With the exception of the line-bisection test, for which neglect was determined by BIT guidelines, patients were considered to exhibit neglect if their left–right difference scores were greater than 20% of the total number of items on each side of the array.\textsuperscript{38} There were five patients who met all criteria for participation. One of these patients exhibited mild neglect and proved to benefit substantially from practice: after three baseline-phase sessions, he performed at ceiling levels (i.e., at maximum possible performance) on most of the experimental tasks; he was subsequently dropped from the study. Patient characteristics of the remaining four patients who met all inclusion criteria can be seen in Table 1, and lesioned regions are shown in Figure 1.

### Treatment Protocol

Participants were given a comprehensive physical examination by the study physician (A.G.), including blood work to assess renal function. An ABA treatment design was used. After starting on placebo (taken in unlabeled 100-mg oral syringes twice daily; A1 phase), subjects were titrated to target-dose amantadine (200 mg, taken in unlabeled 100-mg oral syringes twice a day; B phase) and subsequently titrated down to placebo again (A2 phase). The titration dosing schedule entailed 100 mg (50 mg, twice a day) for 3 days before the target dose and after completion of the B phase. Performance at each testing session was used to assess the stability of scores (described later); consequently, the number of testing sessions in the treatment phase of the study varied across the participants, as follows: subject 1: four sessions in 10 days; subject 2: five sessions in 10 days; subject 3: 10 sessions in 23 days; subject 4: four sessions in 8 days. Participants were tested approximately three times per week by a research assistant who was blinded to the study phase. Testing sessions were all performed at the same time of day for each subject.

At the start of each testing session, blood pressure, pulse, daily caffeine intake, daily cigarette use, sleep start and end times, and intake of daily study medication were monitored; all participants were determined to be stable. Participants and caregivers kept a daily calendar listing the times they took the study drug, as well as their daily sleep start and end times. When necessary, participants were called daily to remind them to take morning and evening study medication.

The study physician was always aware of the participant’s drug status. The tester automatically relayed daily blood pressure and pulse readings outside a specified baseline range to the study physician. Once a week, a side-effect questionnaire was administered to all participants and caregivers, asking them to cooperatively rate the presence of 19 symptoms (e.g., drowsiness, headaches, shortness of breath) on a four-point scale (none, mild, moderate, severe). The results of the questionnaire were routinely reported to the study physician as well. Adverse effects are reported in Table 2. No adverse effects were reported more frequently in the amantadine phase than in the placebo phases.

### Testing Protocol

#### Daily Probes

1. **Letter cancellation**, a subtest of the BIT,\textsuperscript{38} required cancellation of the letters \(E\) and \(R\) printed on 8.5 \(\times\) 11-inch paper. A difference score was obtained by subtracting the number of targets cancelled on the left of the array from the number cancelled on the right.

2. **Line bisection**, another subtest of the BIT, required demarcation of the center of three lines presented on a sheet of paper. The mean distance (in millimeters) of responses from the true midpoint was calculated.

3. **Large-letter cancellation** (Buxbaum and Coslett, unpublished test, 1993) required cancellation of 80 \(T\)s among the letters \(E\) and \(C\) in a large array (34 \(\times\) 22 inches). The difference in the number

### Table 1

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age</th>
<th>Handedness</th>
<th>Education, yrs</th>
<th>Months after CVA</th>
<th>Lesion</th>
<th>Visual Field</th>
<th>Hemiparesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>75</td>
<td>Right</td>
<td>20</td>
<td>35</td>
<td>Thal, IC</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>S2</td>
<td>74</td>
<td>Right</td>
<td>12</td>
<td>31</td>
<td>F, T, P, BG, IC</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>S3</td>
<td>73</td>
<td>Right</td>
<td>20</td>
<td>24</td>
<td>F, T, P, O, Thal</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>S4</td>
<td>78</td>
<td>Right</td>
<td>18</td>
<td>6</td>
<td>F, T, O</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
of items canceled on left vs. right in 2 mins was calculated.

4. The Bell test\textsuperscript{37} required cancellation of bells presented in a dense array on 8.5 × 11-inch paper. A left–right difference score was calculated.

5. Personal neglect was assessed with the Fluff test, which was administered by placing six cotton balls on a blindfolded participant’s left side at the shoulder, chest, elbow, forearm, wrist, and hip (for a similar test, see Cocchini et al.\textsuperscript{39}). On removal of the blindfold, the participant was instructed to locate and remove the cotton balls. The number of detected targets was tallied (0–6).

<table>
<thead>
<tr>
<th>TABLE 2 Adverse effects (n = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adverse Effect</td>
</tr>
<tr>
<td>Dizziness</td>
</tr>
<tr>
<td>Insomnia</td>
</tr>
<tr>
<td>Mental confusion</td>
</tr>
<tr>
<td>Drowsiness</td>
</tr>
<tr>
<td>Depression</td>
</tr>
<tr>
<td>Anxiety</td>
</tr>
<tr>
<td>Hallucinations</td>
</tr>
<tr>
<td>Loss of appetite</td>
</tr>
<tr>
<td>Dry mouth</td>
</tr>
<tr>
<td>Constipation</td>
</tr>
<tr>
<td>Swelling of ankles</td>
</tr>
<tr>
<td>Low blood pressure</td>
</tr>
<tr>
<td>Headaches</td>
</tr>
<tr>
<td>Blurred vision</td>
</tr>
<tr>
<td>Skin rash</td>
</tr>
<tr>
<td>Chest/arm pain</td>
</tr>
<tr>
<td>Shortness of breath</td>
</tr>
</tbody>
</table>

FIGURE 1 Reconstructed lesions of subject 1 (top row), subject 2 (second row), subject 3 (third row), and subject 4 (bottom row).
6. The Sustained Attention to Response Test (SART\textsuperscript{40}) was used to assess attention. Subjects viewed 225 single digits on a computer screen during a 4.3-min period. Each digit was presented for 250 msecs, followed by a 900-msec mask. Participants responded by pressing a mouse key for all digits except the number 3, which appeared 25 times in a quasi-randomized fashion. The number of correctly withheld responses to the number 3 was tallied (maximum = 25).

7. The Dual-Task test is a measure of simple response time with and without a secondary task load.\textsuperscript{41} In the baseline condition (DT base), subjects responded with a key press to 64 black circles 1 cm in diameter appearing in randomized locations on a computer screen at intervals of 500–2000 msecs throughout 64 trials. In the dual-task condition (DT dual), subjects performed the DT base task in conjunction with an oral digit-repetition task conducted at span. Trials in which patients did not concurrently perform both tasks were discontinued and rerun. Interference associated with the secondary task was measured by subtracting the mean response latencies on DT base from DT dual (DT decrement). Mean response latency to ipsilesional (right sided) targets in the baseline condition was used as a measure of simple sensorimotor response time (DT base right). Decrements in response to contralesional targets under dual-task load was measured by subtracting mean response latencies to left targets in DT base from DT dual (L dual – L base).

8. The Lateralized Target and Lateralized Response tasks\textsuperscript{42} measured response latencies in two different stimulus/response conditions. In the lateralized target test of perceptual neglect, subjects viewed three horizontally arrayed, 5-mm dots on a computer monitor. They were asked to fixate on the center dot, and the examiner monitored fixation. After 2000 msecs, a downward-pointing arrow replaced one of the three dots. Participants responded by pressing the spacebar on the computer keyboard when a left or a right arrow was detected. In the lateralized response test of motor or intentional neglect, subjects viewed three horizontally arrayed dots. They were asked to fixate on the center dot and the examiner-monitored fixation. After 2000 msecs, a left-, right- or downward-pointing arrow replaced the center dot. Subjects responded accordingly by pressing a key on a partially shielded keyboard with left, central, and right response areas. In both tasks, nine practice trials were followed by 20 trials each with left, right, and center trials, in randomized order. Mean difference in response time for left vs. right trials was calculated for each subject.

9. Anosognosia questionnaire. At the end of each testing session, a five-question Anosognosia questionnaire\textsuperscript{2} was administered. Two questions addressed awareness of sensorimotor impairment (scores reflect deviation of actual from reported impairment; range, 0–2), and three questions addressed general awareness of deficit (range, 0–2).

**Outcome Measures**

1. The Naturalistic Action Test (NAT).\textsuperscript{43,44} measures everyday action impairment through a standardized three-level performance test. Participants are asked to prepare toast and coffee, wrap a present, pack a lunchbox, and fill a schoolbag. Performance is scored for key steps accomplished and errors committed. The proportion of left-sided objects used and/or touched was also tallied. The NAT has excellent scoring reliability (median weighted kappa for accomplishment score = 0.98), internal consistency (Cronbach alpha = 0.79), concurrent criterion validity with the Functional Independence Measure (FIM) measure ($r = 0.5$), construct validity ($r = -0.68$ with a measure of processing speed/arousal, and 0.61 with a measure of visuospatial attention), and predictive validity. A significant relation was found between discharge NAT and a follow-up instrumental activities of daily living scale in bivariate analysis ($r = 0.58$), and in multiple-regression analyses. The multiple-regression analyses showed that NAT’s success in predicting instrumental activities of daily living was independent of its correlation with FIM score, age, or the various attention measures. NAT outperformed the FIM cognitive score in predicting the instrumental activities of daily living score. It also outperformed each of the attention tests. Finally, the correlation between a second NAT administered at the same time as the instrumental activities of daily living measure was also strong ($r = 0.64$), as was the correlation of the second NAT and the discharge NAT (0.66).\textsuperscript{43,44} Participants performed the NAT in every other testing session.

2. The transfers and mobility items from the FIM instrument\textsuperscript{45} were assessed once during each study phase. Clinicians who had been trained and certified according to Uniform Database System procedures rated the items on a scale of
1 (total assistance required) to 7 (complete independence).

3. The Family Burden Questionnaire (adapted from Friedrich et al.’s Questionnaire on Resources and Stress) is a 10-point true/false questionnaire designed to assess stress placed on the family of the stroke patient (e.g., “_____” is hard to live with; “_____” doesn’t do as much as s/he

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**FIGURE 2** Performance of the four participants in the baseline, treatment, and posttreatment phases of the study on a combined score from the bell test and letter-cancellation test. Each graph depicts data from a single participant.
should do”). The Family Burden Questionnaire was administered to a family member once during each study phase.

### Determination of Performance Stability

Stability in each study phase (A1, B, A2) was determined using a combined score from the bell test and the letter-cancellation task (Fig. 2). The total numbers of items cancelled (of 74) for three consecutive testing sessions were averaged. A moving average was computed that compared the fourth testing session’s total score with the mean of the three previous sessions. Fourth-session scores greater than the mean of the previous sessions were considered unstable. Fourth-session scores more than 10 points below the mean were also considered unstable. The cutoff of 10 percentage points was determined from evaluation of pilot subject performance. Fourth-session scores below the mean yet within 10 percentage points were considered stable, and the study phase was ended. On the basis of this calculation, the number of sessions in each phase varied across subjects, as follows: baseline (A1): subject 1 = 13 sessions; subject 2 = 8 sessions; subject 3 = 5 sessions; subject 4 = 10 sessions; treatment (B): subject 1 = 4 sessions, subject 2 = 5 sessions, subject 3 = 10 sessions, subject 4 = 4 sessions; posttreatment (A2): subject 1 = 4 sessions, subject 2 = 5 sessions, subject 3 = 3 sessions. Unfortunately, subject 4 could not be tested in the A2 phase because of a change in the therapy schedule that precluded continued participation.

In addition, we confirmed stability in the baseline phase with Young’s C statistic, an indicator of serial dependency. The C statistic is not reliable with fewer than eight data time-points; therefore, only data from subjects 1, 2, and 3 were evaluated. Baseline-phase data from all three subjects showed significant serial dependency (i.e., stability): subject 1: \( z = 9.9, P = 0.0001 \); subject 2: \( z = 6.1, P < 0.0001 \); subject 4: \( z = -6.4, P < 0.0001 \).

### TABLE 3 Mean accuracy scores in each treatment phase (percent correct)

<table>
<thead>
<tr>
<th>Measure</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1</td>
<td>B</td>
<td>A2</td>
<td>A1</td>
</tr>
<tr>
<td>Bell cancellation</td>
<td>0.86</td>
<td>0.80</td>
<td>0.91</td>
<td>0.47</td>
</tr>
<tr>
<td>Letter cancellation</td>
<td>0.93</td>
<td>0.93</td>
<td>0.95</td>
<td>0.82</td>
</tr>
<tr>
<td>Large-letter cancellation</td>
<td>0.81</td>
<td>0.87</td>
<td>0.92</td>
<td>0.60</td>
</tr>
<tr>
<td>Fluff test</td>
<td>0.72</td>
<td>0.92</td>
<td>0.95</td>
<td>0.50</td>
</tr>
<tr>
<td>SART correct go</td>
<td>0.78</td>
<td>0.76</td>
<td>0.82</td>
<td>0.72</td>
</tr>
<tr>
<td>SART correct no go</td>
<td>0.44</td>
<td>0.49</td>
<td>0.51</td>
<td>0.82</td>
</tr>
<tr>
<td>Lateralized target: left correct</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95</td>
</tr>
<tr>
<td>response</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean line-bisection error, mm</td>
<td>9.00</td>
<td>16.10</td>
<td>14.50</td>
<td>16.50</td>
</tr>
</tbody>
</table>

### TABLE 4 Mean response latency in each treatment phase, msecs

<table>
<thead>
<tr>
<th>Measure, msecs</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1</td>
<td>B</td>
<td>A2</td>
<td>A1</td>
</tr>
<tr>
<td>Dual-task baseline right</td>
<td>437.3</td>
<td>443.3</td>
<td>406.0</td>
<td>497.3</td>
</tr>
<tr>
<td>Left dual – left base</td>
<td>1639.0</td>
<td>932.8</td>
<td>677.7</td>
<td>3507.0</td>
</tr>
<tr>
<td>Dual-task baseline decrement</td>
<td>1595.3</td>
<td>974.0</td>
<td>715.0</td>
<td>3818.0</td>
</tr>
<tr>
<td>Sustained attention to response test</td>
<td>492.3</td>
<td>473.7</td>
<td>428.0</td>
<td>628.0</td>
</tr>
<tr>
<td>Lateralized target left</td>
<td>455.5</td>
<td>539.5</td>
<td>441.0</td>
<td>1076.7</td>
</tr>
<tr>
<td>Lateralized response left</td>
<td>1530.0</td>
<td>1563.8</td>
<td>1537.0</td>
<td>1893.3</td>
</tr>
</tbody>
</table>
### RESULTS

Tables 3 and 4 provide the mean performance in each study phase on probe tests. Table 5 presents data from the outcome measures (NAT, Anosognosia questionnaire, FIM instrument, and Family Burden Questionnaire).

Linear regressions were performed with many of the probe tests to determine whether amantadine improved performance. The measures presented in Tables 2 and 3 were used as dependent variables, with the exception of the bell, letter, and large-letter tasks, for which we employed right–left difference scores. Visual inspection of the data revealed large practice effects in some subjects; therefore, only the last three placebo sessions were included. Sessions in which drug dose was being titrated up or down were not included. The session variable permits assessment of whether linear trends are present in the data (e.g., practice effects and increasing better performance with each session), whereas the drug variable, if significant, indicates that on-amantadine sessions differ significantly from off-amantadine sessions. The direction of any significant effects (positive or negative) must then be ascertained by examination of the data.*

With the threshold for significance set at an arguably liberal P value of <0.05 (i.e., uncorrected for multiple comparisons), subject 1 showed neither negative nor positive effects on any measure. Subject 2 showed a significant positive response on SART mean response time (standard coefficient = −0.43, P = 0.04) and on lateralized mean response time (standard coefficient = −0.61, P = 0.04), and negative responses on DT base response time (standard coefficient = 0.81, P = 0.001) and SART no-go correct responses (standard coefficient = −0.32, P = 0.01). Subject 3 showed a positive response on SART mean response time (standard coefficient = −0.31, P = 0.02) and a negative response on lateralized mean response time (standard coefficient = 0.47, P = 0.04). Subject 4 showed a positive response on lateralized mean response time (standard coefficient = −1.3, P = 0.002).

### DISCUSSION

We performed a double-blind, placebo-controlled exploratory study of the effects of amantadine, a glutamate antagonist, in four patients with moderate to severe chronic neglect. Participants were varied in their underlying neuropathology: one had a pure subcortical lesion, two were mixed cortical and subcortical, and one was purely cortical. Despite careful efforts to establish stable performance baselines before entering the drug-treatment phase of the study, there were no participants for whom amantadine had an unambiguously positive result, and the few positive responses on individual tests were quite modest. There were also scattered negative responses. Encouragingly, most adverse effects were reported infrequently, with comparable frequencies between drug and placebo conditions. Thus, additional studies of amantadine in this population seem both safe and feasible.

There are several possible reasons for the failure of amantadine to ameliorate neglect in the present group of patients. First, it might be argued that lesions were too extensive in the present group, affecting numerous brain regions aside from the putatively critical striatum. This is indeed true of subjects 2 and 3; however, subjects 1 and 4 had relatively small lesions. Second, it may be the case that the dosage of amantadine was inappropriate, despite our adherence to medication guidelines. Nevertheless, additional testing with a different (likely, larger) dose of medication would be required to address this possibility. Third, it may be

### TABLE 5 Mean test scores on Naturalistic Action Test (NAT), Functional Independence Measure (FIM), and questionnaires

<table>
<thead>
<tr>
<th>Measure</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAT total score (18 possible)</td>
<td>A1</td>
<td>B</td>
<td>A2</td>
<td>A1</td>
</tr>
<tr>
<td>NAT left objects touched/used, %</td>
<td>7</td>
<td>8</td>
<td>11</td>
<td>8.3</td>
</tr>
<tr>
<td>FIM locomotion ratings (7 possible)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>FIM transfer ratings (7 possible)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Family Burden questionnaire (no. true/10)</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Anosognosia questionnaire (maximum = 8)</td>
<td>3.3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Before performing regression analyses, the Durbin–Watson statistic, a measure of autocorrelation, was determined for each measure. None of the measures showed significant autocorrelation.
that amantadine would function effectively as an adjuvant to other behavioral treatment.

Given the serious effect of neglect on patient and caregiver functioning and quality of life, considerable efforts have been devoted to exploring potential therapeutic and treatment approaches to the disorder. Pierce and Buxbaum\(^49\) provide a detailed review of treatment approaches, which include treatments targeting arousal, phasic alerting treatments, hemispheric activation approaches, constraint-induced therapy, mental imagery training, prism treatment, eye patching, caloric stimulation, optokinetic stimulation, neck-vibration therapy, and trunk-rotation therapy. With the possible exception of prism treatment, which shows promise,\(^50,51\) many of these treatment approaches have had equivocal, contradictory, or quickly fading effects. Further study will be required to determine whether amantadine falls into this category as well. At the least, the failure of amantadine to improve performance in any of the current patients indicates that any potential benefit is not universal.

An unintended but important product of this study was a striking illustration of the extreme day-to-day variability in baseline (off treatment) performance that may be observed in neglect patients.\(^52,53\) It is well appreciated that nonlateralized deficits in attention and arousal are a prominent component of the neglect syndrome.\(^54–57\) It is also likely that levels of arousal may fluctuate in neglect in response to a number of internal and external variables. For example, performance on neglect tasks is improved by the presentation of simple alerting tones, and by self- or other instructions to “wake up.”\(^58\) In the present study, it is of interest that day-to-day fluctuations seemed to decrease with practice (see Fig. 2), suggesting that attentional variability may be modulated by the automaticity with which tasks can be performed. The sensitivity of neglect to general attentional factors may obscure subtle treatment effects, or, conversely, they may inflate the apparent effects of a given treatment. In addition, not all of the tests fluctuated together (i.e., improvement on one task was sometimes accompanied by worsening on another), suggesting that factors other than attentional variations affected performance. The present results thus underscore the need for caution in interpreting positive (or negative) treatment results when studies do not employ an ABA design with careful baseline assessment. The data also suggest that when conducting medication-treatment studies with neglect patients, a lengthy time frame spanning numerous weeks may be necessary.

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Kinematic Aiming Task
Measuring Functional Changes in Hand and Arm Movements After Botulinum Toxin-A Injections in Children with Spastic Hemiplegia

ABSTRACT

Objective: To describe different aspects of a kinematic aiming task (KAT) as a quantitative way to assess changes in arm movements within 2 wks after botulinum toxin-a (BTX-A) injections in children with spastic hemiplegia.

Design: Intervention study randomized clinical trial; follow-up within 4 wks after baseline measurement.

Results: The KAT gave a high intraclass correlation on movement time, spread of end points (END), and index of performance effective (IP-E). After BTX-A, a significant increase of END and IP-E was shown if precision demand in the KAT was high, whereas the inverse occurred when speed was more important. These functional changes coincided with a significant decrease of the maximum voluntary contraction of the flexor muscles of the forearm. Muscle tone measured with the Ashworth scale did show a nonsignificant decrease of muscle tone, as did the stretch restricted angle and the active and passive ranges of motion of the elbow and wrist.

Conclusions: Muscle force decreased immediately after BTX-A, showing the direct effect of BTX-A. The KAT is an adequate, reproducible way to quantify functional changes after BTX-A in the upper limb. BTX-A has an inverse effect in the precision task when accuracy is important, and it has a positive effect when speed prevails.

Key Words: Cerebral Palay, Kinematic Aiming Task, Spasticity, Upper Limb, BTX-A, Ashworth Scale, Tardieu Scale
Children with congenital spastic hemiplegia show poorer manual skills with their affected side. The most frequently mentioned causes for this loss of function are related to degrees of spasticity and increased muscle tone, decreased muscle power, and decreased muscle length. A lot of research has been directed to the functional relation between spasticity and manual skills in children with cerebral palsy (CP). Level of spasticity is most often graded by the Ashworth scale (AS) and the Tardieu test (TT). Reduction of spasticity, however, is not automatically related to improvement in manual skills. Indeed, low correlations have been found between levels of spasticity and outcome measures of skilled motor control. Several explanations for this low correlation have been put forward. Both AS and TT score the increased resistance against a high-velocity stretch. The TT uses the difference between the joint angle at the moment of the high-velocity resistance (stretch restricted angle [SRA]) and the low-velocity angle (passive restricted angle [PRA]) as a measure of the dynamic component of muscle tone abnormality. However, this increased resistance is probably not just a measure of spasticity. It is also related to myogen and collagen stiffness. Scholtes et al. even have stated that the solitary use of the SRA for evaluation of treatment of spasticity is probably better because of the interest in high-velocity stretch as a measurement of velocity-dependent resistance. Damiano et al. have shown that the TT seems to be somewhat task dependent. TT was measured by resistance torque at three velocities, during passive knee flexion and extension, combined with EMG. TT showed weak to moderate relationships with knee motion during gait. This underlines the need to have performance tasks that are close to daily life behavior. Related to the leg, such studies are performed using gait parameters to quantify change in walking performance. In accordance with the walking performance, we developed a visual guided aiming task with quantitative parameters as speed and accuracy to measure whether differences in the parameters of the arm movements could be reproduced reliably over time, and whether the task would be sensitive enough to measure change after intervention. This task, which has been called the kinematic aiming task (KAT), uses two simple visual guided aiming movements, with low memory and cognitive load. In many ADL tasks, the reaching, grasping, and pointing of objects are part of the task. Therefore, this task focuses on grasping and holding an object as well as transferring it with one hand to a new target position and adapting the movement to the task requirements. In the present study, we are specifically interested in subtle quantitative changes after botulinum toxin-A (BTX-A) injections, because of the ascribed effect in reducing spasticity and muscle force. To test our KAT, we measured changes in the performance of children with spastic hemiplegia with the affected hand, before and after BTX-A injection in the muscles of the wrist and elbow, compared with a non-treatment group.

We wanted to test the following questions:

1. How reproducible is the current KAT in the nontreatment group of CP children?
2. Are the main outcome measures of the present KAT related to spasticity as measured with AS and SRA, range of motion, and maximum voluntary contraction (MVC)?
3. Does MVC of the finger flexors decrease in the injected arm?
4. Do the KATs detect changes after treatment (BTX-A)?

METHODS
Participants

For this study, the same children were enrolled as in the study of Speth et al.: namely, 20 children with CP (aged 4–16 yrs [mean 9.5] with diagnoses of hemiplegia according to Hagberg classification and the hand function according to Zancolli classification (pattern I, IIa, or IIb). Zancolli patterns are described as

Zancolli I: active finger extension with less than 20 degrees of wrist palmar flexion;
Zancolli IIa: active finger extension with more than 20 degrees of wrist palmar flexion and wrist dorsal flexion possibility with fisted hand; and
Zancolli IIb: active finger extension with more
than 20 degrees of wrist palmar flexion and no possibility of dorsal flexion of active wrist.

Children with hand function according to Zancolli III were excluded because of their inability to extend the wrist and actively grasp and hold an object with the affected hand. No children with asymmetric mild quadriplegia or diplegia were included in this study. Table 1 provides an overview of the baseline characteristics of the participants. The parents gave informed consent, and the medical ethics committee of the Rehabilitation Foundation Limburg approved the study.

Design

Matching according to age and Zancolli level resulted in ten pairs of children. One child of every pair was randomly allocated to either the treatment or the nontreatment group. Each child was tested twice. First, the baseline measurement was administered. Then, after 1 mo, each child was tested again. For the treatment group this meant the baseline measurement was taken about 14 days before the child received BTX-A, and the second measurement was taken about 14 days after BTX-A.

The examination consisted of spasticity assessment (AS and SRA), passive and active range of motion (PROM and AROM), MVC, and the visually guided aiming task (KAT).

### Injection Technique and Dosage

Bottox from Allergan was used (dilution 5 U/0.1 ml). Dosage was 2–3 U/kg body weight per muscle in the upper arm, 1–2 U/kg body weight per muscle in the forearm, with a maximum of 50 U at any one injection site, with an overall maximum dose of 400 U per total body weight. Predominantly, the m. adductor pollicis (10 U), the m. flexor carpi ulnaris (2 U), and the m. pronator teres (30–50 U) were injected, and less frequent injections were given in the m. flexor carpi radialis (30 U to 2 × 40 U), m. biceps brachialis (2 × 20 U to 2 × 50 U), m. brachioradialis (40 U to 2 × 40 U), and m. flexor pollicis brevis (5 U). The number of units per total body weight varied from 2.9 to 5.8 U.

For a more detailed description of dose and localization, see Speth et al. 

### Outcome Measures

Outcome measures are divided according to measures of the level of function and the level of activity, according to the International Classification of Functioning, Disability and Health.

### Function Level

#### Muscle Tone

Spasticity was measured in supine position using the AS and SRA.

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| TABLE 1 Baseline characteristics and scores of all 20 children with CP |
|-----------------------------|-----------------------------|-----------------------------|
| Side paresis, frequency     | 9 right; 1 left             | 3 right; 7 left             |
| Mean age, yrs               | 9.4 (5 to 16)               | 9.7 (4 to 16)               |
| Sex, frequency              |                             |                             |
| Female                      | 5                           | 6                           |
| Male                        | 5                           | 4                           |
| Zancolli, frequency         |                             |                             |
| I                           | 4                           | 5                           |
| II A                        | 4                           | 1                           |
| II B                        | 2                           | 4                           |
| Ashworth wrist, frequency   |                             |                             |
| 0                           | 7                           | 5                           |
| 1                           | 2                           | 4                           |
| 2                           | 1                           | 1                           |
| Ashworth elbow, frequency   |                             |                             |
| 0                           | 3                           | 3                           |
| 1                           | 6                           | 5                           |
| 2                           | 1                           | 2                           |
| Stretch restricted angle—wrist, deg | 60 (30 to 90) | 52.5 (15 to 90) |
| Stretch restricted angle—elbow, deg | 160 (100 to 180) | 127.5 (50 to 180) |
| Active dorsal flexion—wrist, deg | −18 (−51 to 45) | −6 (−55 to 55) |
| Active extension—elbow, deg | 170 (135 to 180)           | 170 (140 to 180)           |
| Passive dorsal flexion—wrist, deg | 70 (65 to 90) | 67 (50 to 90) |
| Passive extension—elbow, deg | 180 (150 to 180)           | 180 (160 to 190)           |
| Maximal voluntary contraction flexors—wrist/fingers, N | 9.9 (2.1 to 23) | 8.9 (2 to 19.5) |
The muscle tone of wrist the and elbow were measured with the original five-point AS. The SRA was assessed by moving the wrist and elbow as quickly as possible (within 1 sec) through the whole range of motion. SRA was measured with manual standardized goniometry (MIE Medical Research Ltd clinical goniometry).

**Range of Motion**

**AROM and PROM of the elbow and wrist were measured in a sitting position, using the same goniometry**

**Muscle Force**

Muscle force was evaluated using a method that has been described previously. The MVC of the finger and wrist flexors was measured (in newtons) in a task in which subjects had to apply maximum pressure onto the end of a high-quality strain lever. The pressure was transmitted onto a force transducer.

**Activity Level**

**Kinematic Aiming Tasks**

The kinematic aiming tasks (KAT) consisted of two different kinds of tasks: the discrete task and the continuous task.

One task was called the discrete task and focused on precision in performance. This task is expected to be sensitive to adaptations in force recruitment. In the discrete task, the children had a custom-made puppet (7-cm height, 2.5-cm width) in their spastic hand and could directly see their movements. An LCD screen, which could record the x and y coordinates of the moving object, was placed in horizontal position in front of the child. Oasis software was used to program four conditions, which were expected to be easy enough for children with spastic hemiplegia to perform. The conditions were (a) movement for 10 cm to a 5-cm target (condition 1); (b) movement for 10 cm to a 2.5-cm target (condition 2); (c) movement for 20 cm to a 5-cm target (condition 3); and (d) movement for 20 cm to a 2.5-cm target (condition 4).

The goal for the children was to get the puppet (2.5-cm diameter) exactly in the target circle (2.5- or 5-cm diameter) while performing a substantial arm movement (10 or 20 cm) on a digitizer (Wacom, type Cintiq 18sx, sample rate 206 Hz). This digitizer served as an SXGA full 24-bit color LCD monitor. The surface of the digitizer was made of glass, which made the sliding movement very easy to perform. This is illustrated in Figure 1. After putting the puppet on the digitizer in the starting circle, the investigator pressed the start button. After a random period (0.5–1.5 secs), a tone sounded and the target appeared on the digitizer. This was the go signal for the child, who was then required to move as quickly and as accurately as possible to the target by shifting the puppet to the target that had appeared on the other side. After placing the puppet in the target, the child had to stop and wait for a new auditory go signal. Ten movements were made in each condition. The four conditions were presented in the same order with increasing difficulty (conditions 1, 2, 3, and 4). After a practice session, the experiment started.

After a practice session, the experiment started. The second task, termed the continuous task, focused on movement speed; within 20 secs, as many movements as possible had to be made between the presented targets in the same four conditions.

After putting the puppet on the left side of the digitizer in the starting target area, the investigator pressed the start button. After a random period (0.5–1.5 secs), a tone sounded, and the right target appeared on the digitizer. This was the go signal for a series of back-and-forth movements between two positions. Because the starting position was still visible, it was possible to come back to the start position after reaching the target. After 20 secs, an automated auditory stop signal was given. Conditions were presented in the same order as in the discrete task. Discrete and continuous tasks were randomly performed, and after each task, a rest of at least 2 mins was included.

**Signal Analysis**

In the KAT, both movement speed and accuracy are combined. The relationship between movement speed and accuracy in goal-directed movements is expressed in the speed-accuracy tradeoff. This can be used to equate the processing ability or performance of the motor system by the Index of Performance Effective (IP-E). In for-
The formula format, the definition is:

\[ \text{Ip-E} = a + b \times \log_2 \left( \frac{A}{ETW} \right)/MT \]

where \( a \) and \( b \) are empirical constants, \( A \) = distance between targets, \( ETW \) = effective target width, and \( MT \) = movement time. The ETW is calculated as the target size plus the distance between the center of the target and the center of the puppet.\(^{31}\)

Movement time (secs) per segment was computed from the moment the puppet left the start area until it entered the target area. Spatial accuracy was calculated in two ways: first as a clear dichotomy between the correct (hit) and incorrect (no hit) ending of the movement within the target area (percentage of successful movements [PSM]). Second, the distance of the center of the puppet to the center of the target area was calculated. This distance was taken as a measure for end point spread (END). IP-E (bits/sec) was calculated.

**Statistics**

Reproducibility of both KAT and MVC measurement were measured with intraclass correlation (ICC) for the nontreatment group within 1 mo.

The dependent variables PSM, END, MT, and IP-E were evaluated by means of the general linear model (polynomial), repeated-measures design, with group (2) and session (2) as between-subjects variables and task (2), amplitude (2), and target size (2) as within-subject variables. Alpha level was set at 0.05. Post hoc analysis was done when appropriate.

The changes between the two measurements of the baseline values of MVC, SRA, AROM, and PROM of the elbow and wrist also were calculated. Because of the non-Gaussian distribution of the data, the Mann–Whitney \( U \) test was used to assess the differences in the changes from baseline to the second measurement between the two groups.

Spearman rank correlation was used to examine whether clinical measures (AS, SRA, AROM, PROM, and MVC) at baseline correlated with the PSM, END, MT, and IP-E in both KATs. Statistical significance was set at 0.01 to account for the use of multiple comparisons.

**RESULTS**

No significant differences between groups were found for any of the baseline variables.

**Reproducibility (Test–Retest Reliability)**

An overview of ICCs of the PSM, END, MT, and IP-E in both KATs and of MVC in the MVC task is given in Table 2. High ICCs were found for all outcome measures in both KATs and in the MVC task, indicating a high reproducibility.

**Correlation Between Clinical Measures and Functional Outcome Measures**

At baseline, the outcome measures of the KAT were correlated with the AS, SRA, AROM, PROM, and MVC. The only significant correlation was seen in AROM of the wrist with PSM and END in both tasks (for \( P \) values, see Table 3). No significant correlation was found with any of the tests to score spasticity, illustrating the lack of correlation between KAT outcome measures and clinical measures.

**TABLE 2 Intraclass correlation of percentage of successful movements, end point spread, movement time, and index of performance effective for nontreatment group in discrete and continuous tasks, and of maximum voluntary contraction (MVC) measurement in the MVC task**

<table>
<thead>
<tr>
<th>Intraclass Correlation (ICC) for Nontreatment Group</th>
<th>Discrete Task</th>
<th>Continuous Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAT task</td>
<td>ICC</td>
<td>ICC</td>
</tr>
<tr>
<td>PSM</td>
<td>0.89</td>
<td>0.95</td>
</tr>
<tr>
<td>END</td>
<td>0.87</td>
<td>0.78</td>
</tr>
<tr>
<td>MT</td>
<td>0.81</td>
<td>0.90</td>
</tr>
<tr>
<td>IP-E</td>
<td>0.95</td>
<td>0.89</td>
</tr>
<tr>
<td>MVC task</td>
<td>ICC</td>
<td>0.99</td>
</tr>
</tbody>
</table>

**TABLE 3 Correlation between Ashworth scale, stretch restricted angle, active range of motion (AROM), and passive range of motion of wrist and elbow, maximal voluntary contraction, and percentage of successful movements (PSM), movement time, end point spread (END), and index of performance effective in discrete and continuous tasks; only significant correlations are presented**

<table>
<thead>
<tr>
<th>Spearman Correlation</th>
<th>PSM Discrete</th>
<th>PSM Continuous</th>
<th>END Discrete</th>
<th>END Continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>AROM</td>
<td>0.78</td>
<td>0.649</td>
<td>−0.616</td>
<td>−0.77</td>
</tr>
<tr>
<td>Wrist</td>
<td>0.000</td>
<td>0.002</td>
<td>0.004</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Effect of BTX-A

As seen in Table 4, no significant changes in differences were measured after BTX-A between the treatment and nontreatment groups on SRA, AROM, and PROM. However, a significant median decrease in MVC of 4 N (minimum: 0.9; maximum: 8.5) ($P_{\text{H11021}} < 0.001$) occurred in the treatment group; no change was observed in the nontreatment group.

**PSM and END**

The first important property of the KAT was that both different tasks were easy enough for the children to perform successfully with their affected hand. Generally, children in both tasks reached the target in 70% (SD 29) of the movements. The treatment group succeeded at baseline in 71.7% (SD 29) of the movements and post–BTX-A 69.3% (SD 28), the nontreatment group (69.7% (SD 28) and 69.4% (SD 29). The treatment group showed a nonsignificant decrease of 2.4% after BTX-A. This was mainly caused by the most difficult condition (2.5-cm target, 20-cm distance) in both tasks. A main effect for task was found ($F_{1,36} = 40.69, P < 0.001$), indicating that the tasks differed in accuracy. For the treatment group, the PSM changed in discrete tasks from 82.9% (SD 24) to 79% (SD 23) and in continuous tasks from 60.6% (SD 31) to 59.6% (SD 30). In the nontreatment group, these values were 75.7% (SD 27) and 76.8% (SD 26) in discrete tasks and 63.7% (SD 28) and 62.1% (SD 32) in the continuous tasks.

When examining END, a main effect for task was again found ($F_{1,36} = 5.15, P < 0.03$), along with an interaction with group, session, target size, and target width ($F_{1,36} = 4.95, P < 0.04$), indicating that both groups had different spreads of the end points in different conditions after BTX-A, but approximately equal END values in the discrete task (1.5 cm [SD 0.8]) and in the continuous task (1.8 cm [SD 0.9]).

Post hoc analysis of combined tasks did show a significant interaction with group, session, target size, and target width ($F_{1,76} = 5.334, P < 0.03$). As shown in Figure 2, an increase in END occurred after BTX-A, especially for the large movements.

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**TABLE 4** Changes in median scores of stretch restricted angle (SRA), active range of motion (AROM), and passive range of motion (PROM) in wrist and elbow, and maximal voluntary contraction (MVC) in the treatment and nontreatment groups

<table>
<thead>
<tr>
<th>Change in Median Score</th>
<th>Treatment Group ($n = 11$)</th>
<th>Nontreatment Group ($n = 11$)</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRA wrist, deg</td>
<td>0 (−10 to 30)</td>
<td>0 (−10 to 30)</td>
<td>0.9</td>
</tr>
<tr>
<td>SRA elbow, deg</td>
<td>5 (−30 to 70)</td>
<td>0 (−35 to 50)</td>
<td>0.9</td>
</tr>
<tr>
<td>AROM dorsal flexion wrist, deg</td>
<td>12.5 (−4 to 82)</td>
<td>3 (−31 to 71)</td>
<td>0.2</td>
</tr>
<tr>
<td>AROM extension elbow, deg</td>
<td>5 (−20 to 20)</td>
<td>0 (−20 to 30)</td>
<td>0.4</td>
</tr>
<tr>
<td>PROM dorsal flexion wrist, deg</td>
<td>0 (−10 to 10)</td>
<td>0 (−25 to 15)</td>
<td>0.9</td>
</tr>
<tr>
<td>PROM extension elbow, deg</td>
<td>0 (−10 to 20)</td>
<td>0 (−5 to 10)</td>
<td>0.6</td>
</tr>
<tr>
<td>MVC, N</td>
<td>4 (−0.9 to 8.5)</td>
<td>0 (−0.6 to 0.6)</td>
<td>0.005</td>
</tr>
</tbody>
</table>

$P$ values are based on comparisons between the treatment and the nontreatment groups for change from baseline. Between brackets, minimum and maximum scores are represented.22

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**FIGURE 2** End point spread for both treatment groups (A) and nontreatment groups (B) for both KAT tasks combined (discrete and continuous), pre (baseline) and post (post–BTX-A or second measurement). Condition 1 = (target width 5 cm, target distance 10 cm); condition 2 = (target width 5 cm, target distance 20 cm); condition 3 = (target width 2.5 cm, target distance 10 cm); and condition 4 = (target width 2.5 cm, target distance 20 cm). Bars represent 1 SE. *Significant at 0.05 level.
indicating that larger amplitudes led to poorer accuracy after BTX-A.

**Movement Time**

Main effects for task \( (F_{1,36} = 80.49, P < 0.001) \), target width \( (F_{1,36} = 68.95, P < 0.001) \), and target size \( (F_{1,36} = 22.38, P < 0.001) \) were found for this parameter. A trend for differences with session, group, target size, and width and task occurred \( (F_{1,36} = 3.01, P = 0.09) \). As seen in Figure 3 after BTX-A, the treatment group moved slightly more slowly in the discrete task.

**FIGURE 3** Movement time for both treatment groups (A and C) and nontreatment groups (B and D) in discrete and continuous tasks, pre (baseline) and post (post–BTX-A or second measurement). Condition 1 = (target width 5 cm, target distance 10 cm); condition 2 = (target width 5 cm, target distance 20 cm); condition 3 = (target width 2.5 cm, target distance 10 cm); and condition 4 = (target width 2.5 cm, target distance 20 cm). Bars represent 1 SE. As can seen in panels B and D, the reproducibility of this task is high.

**FIGURE 4** Index of performance effective (IPE) for both treatment groups (A and C) and nontreatment groups (B and D) in discrete and continuous tasks, pre (baseline) and post (post–BTX-A or second measurement). Condition 1 = (target width 5 cm, target distance 10 cm); condition 2 = (target width 5 cm, target distance 20 cm); condition 3 = (target width 2.5 cm, target distance 10 cm); and condition 4 = (target width 2.5 cm, target distance 20 cm). Bars represent 1 SE. As can be seen for controls, the reproducibility of this task is high. *Significant at 0.05 level.
and more quickly in the continuous task, except for the most difficult condition (target 25 cm, distance 20 cm).

IP-E

A significant interaction for IP-E between task, target size, distance, group, and session was found ($F_{1,36} = 6.09, p < 0.03$), indicating that performance was different for both groups, tasks, and sessions.

As can be seen in Figure 4, controls performed similarly in both tasks in all conditions. The treatment group, however, showed a slight decrease in performance in the discrete task, which focused on accuracy, in all conditions. In the continuous task, which is targeted on speed, a slight increase in performance was shown in the treatment group after BTX-A, except for the most difficult (target 2.5 cm, distance 20 cm) condition. After BTX-A, the treatment group showed a specific decrease in that most difficult condition of IP-E (0.5 bits/sec). Post hoc analysis showed that only in the continuous task, an interaction with session, group, target width, and size was reliable ($F_{1,36} = 9.58, p < 0.005$).

DISCUSSION

Our study describes two different tasks of the KAT to assess functional changes in the hand and arm movements in a quantitative way within 2 wks after BTX-A in children with spastic hemiplegia.

The first aim was to determine whether the outcomes of the KAT were stable over time. As seen in Table 4, the ICCs for the KAT are high for the nontreatment group when tested within 1 mo. The high reproducibility indicates that the KAT is an adequate instrument to measure quantitative changes in manual ability of the spastic arm. Furthermore, the high percentage of correct trials showed that neither task is too complex for children with spastic hemiparesis.

No significant correlations were found between spasticity scores at baseline (AS and SRA) and kinematic outcomes in the KAT. One possible reason for this lack of correlation is that the measured resistance is composed of several factors such as spasticity, muscle stiffness, and contractures. Furthermore, one may expect that scores obtained by passive tests, such as AS and PRA, are not comparable and, therefore, are not fully predictive of measures obtained during active motor control tasks, or that AS and SRA are not usable tests.

However, significant correlations were found between wrist AROM with PSM and END in the KAT, suggesting that wrist AROM is probably more predictive of manual task performance than is muscle tone. If a greater wrist AROM was present, a higher PSM and a lower END were seen. This indicates that wrist AROM might be more important for selecting patients for treatment than AS or SRA, and it might indicate good selective motor control of the wrist.

With respect to the questions about the direct effects of BTX-A, a significant reducing effect was confirmed by the significant decrease in MVC of the forearm flexors within 2 wks after BTX-A injections. This decrease in MVC is caused by decreased M-reflex and the blocking of a large number of motor units after BTX-A in the injected muscles, thus introducing “paresis.”

A nonsignificant reduction in muscle tone and increase in AROM has already been shown in the study of Speth et al. One possible reason for the lack of significance could be that the treatment group was heterogeneous and too small. In other placebo-controlled studies, significant short-term effects on the muscle tone and AROM of the wrist after BTX-A (2–6 wks) have been shown for spasticity.

The most important question was whether there is a detectable effect of BTX-A on the KAT outcome measures. The PSM did change slightly in the treatment group (small decrease of 2.9% after injections) in both tasks, and the nontreatment group maintained the same percentage of PSM. Overall, the treatment group showed increases in END after BTX-A injections, and this effect was significant in the most difficult condition. No changes were seen in the nontreatment group. If more accuracy was asked and more distance had to be covered, END enlarged after BTX-A. Overall, MT showed no significant change. MT increased in the discrete task, but in the continuous task a decrease was seen, except for the most difficult condition. This difference in MT between the two tasks leveled out the effect over all conditions. Because of BTX-A, a lower speed induced muscle hypertonia, and increases in AROM and PROM were expected, creating the possibility for faster movements, especially in an ongoing movement task such as the continuous task. Indeed, this was found in all conditions except for the most difficult condition, in which the opposite occurred. Probably, the specific demand of accuracy in the most difficult condition was so high that MT had to increase. In the discrete task, the movement time increased in all conditions, indicating that the accuracy demand and the exact braking within the target area slowed down the movement. The increase of movement time in the discrete task could also be explained by a decrease of muscle power after BTX-A. When less muscle activity can be generated and discrete movements are required, MT can increase if the accuracy demand is high and if more force is needed to control the movement. In the continuous task, in contrast, accuracy demands are
not high, and the effects of a decrease of muscle tone seem to be more beneficial than the negative impact caused by loss of force.

With respect to the IP-E in the continuous task, an expected increase occurred after BTX-A, because the children were able to move more quickly. A decrease in IP-E occurred only in the most complex condition, when the accuracy demand was very high. In general, performance after BTX-A decreased in the discrete task. Again, an increased accuracy demand results in decreased performance after BTX-A.

Limitations of the KAT

The presentation of the tasks in the same order with increasing difficulty was chosen because randomization made the test far too confusing for the children, and they had difficulty complying with the demands. Possibly, fatigue at the moment of the last, most complex condition could occur. However, the results on END and MT showed no clear indication for fatigue. If fatigue had occurred, more END would have been expected in the last test condition, and MT would have increased. This was not observed. In fact, END was lower for the most difficult condition 1.3 (SD 0.6) than for the most easy condition 1.5 (SD 0.9). MT did increase slightly from 0.7 (SD 0.2) to 1 (SD 0.3) in the most difficult condition.

CONCLUSION

The KAT seems to be an adequate, reproducible way to quantify functional changes after BTX-A in the upper limb, especially in the most complex condition and in the continuous task. The KAT is very easy to perform for the children and applicable in clinical settings.

Only AROM of the wrist showed a positive correlation with the KAT outcome measures.

BTX-A seems to have a direct, inverse effect on MT, END, and IP-E in the discrete tasks, when a high appeal is made on the accuracy and control of braking movements. On the other hand, there is a positive effect on MT and IP-E in continuous tasks, when speed is important and less accuracy is demanded.

Muscle force decreased immediately after BTX-A, showing the direct effect of BTX-A.

REFERENCES


Effect of Treadmill Training with Body Weight Support on Gait and Gross Motor Function in Children with Spastic Cerebral Palsy

ABSTRACT


Objective: To examine the effect of treadmill training with body weight support (TBWS) on gait and gross motor function in children with spastic cerebral palsy (CP).

Design: Eight children with spastic CP participated in the study. Their temporal-distance gait parameters, Gross Motor Function Measure, muscle tone, and selective motor control were assessed three times: two times under their regular therapeutic treatment (condition A), and one time after receiving the TBWS treatment in addition to their regular therapeutic treatments (condition B). There were two treatment schedules, AAB and ABA. Except for the first one (taken at study entry), the assessments were always taken after 12 wks of treatment. The children were equally divided into two groups and randomly assigned to the two schedules. The two groups were matched according to category of the Gross Motor Function Classification System.

Results: The TBWS treatment significantly improved the children’s gait (increases in stride length and decreases in double-limb support percentage of gait cycle) and their Gross Motor Function Measure (dimension D and E scores as well as the total score). No significant improvements on muscle tone or selective motor control were noted.

Conclusions: The TBWS treatment improved some gait parameters and gross motor functions in children with spastic CP.

Key Words: Gait Training, Cerebral Palsy, Gross Motor Function, Total Body Weight Support
Independent walking represents a hallmark of motor development and independence in functional mobility. It also provides children with the chances to explore the environment, broaden the minds, and participate in social activities. Therefore, endeavoring to improve the motor function, especially the independent ambulation of children with cerebral palsy (CP), is one of the important missions for clinicians.

Many different rehabilitation approaches for children with CP were adopted in clinics, each with a different philosophy. For example, according to the neurodevelopmental treatment (NDT) or the Bobath concept, gait training for walking should begin with the preparation of the motor components that can be found in an easier task (e.g., balance in standing). Once the components are trained, the effect is expected to transfer from the easier task to the harder one. However, studies have challenged the philosophy of NDT and its treatment effect. For example, it has been shown that weight shifting in standing is qualitatively different from weight shifting in walking, and training on the former did not necessarily transfer to the latter. In general, training on standing balance had an effect on standing balance only—not on walking or on the symmetry of gait.

A different philosophy is that of the task-oriented approach. The approach stresses the importance of matching the training task with the functional goal of the target task. According to this approach, the best way of training walking is to practice walking itself. It has been demonstrated that the effect of training was specific to the particular characteristics of the task being trained on.

One illustration of the task-oriented approach is treadmill training with body weight support (TBWS). It consists of a motor-driven treadmill with a harness that suspends the patient’s body weight. Because the needs for body weight support and balance control are released with such a system, training with repetitive gait cycles can be provided for patients with spinal cord injuries or strokes, even at the early stages of recovery. Promising results have been reported in the literature in these patients. TBWS has also been shown to facilitate early ambulation in young children and children with Down syndrome. However, studies that have applied TBWS for gait training in children with CP are limited in the literature.

Richards et al. first investigated the feasibility of applying treadmill gait training to four young children with spastic CP (1.7–2.3 yr old) four times per week for four months. They showed that treadmill training was feasible even before the children had developed the ability of independent walking. Schindl et al. conducted a similar study of TBWS gait training in six nonambulatory children with CP and in four children with CP who were ambulatory but who needed varying degrees of support. Their results show that after a 3-mo program (30 mins per session, three sessions per week, 36 sessions overall), the children demonstrated significant improvements of motor function. Day and colleagues also have presented a case of nonambulatory child with spastic tetraplegic CP who benefited from locomotor training with TBWS. In the present study, we examined the effect of a 12-wk TBWS program on the gait, gross motor function, muscle tone, and selective motor control in children with spastic CP.

**METHOD**

**Experimental Design**

The study adopted a within-participant design with just one factor—that is, the type of treatment. All the participants received their regular therapeutic treatment before receiving the experimental treatment, which was the TBWS gait training plus their regular treatment. They were assessed three times. There were two kinds of assessment schedules, each assigned to one group of participants. For the first schedule (AAB), the participants were assessed once at study entry and a second time 12 wks later, before receiving the experimental treatment. The experimental treatment lasted for another 12 wks. The third assessment took place right after the experimental treatment. For the second schedule (ABA), the participants were also assessed once at study entry. Then, they received 12 wks of experimental treatment before being assessed a second time. Another 12 wks of regular treatment elapsed before the third assessment was administered. The second assessment in the AAB schedule allowed us to examine whether the participants’ performance might change simply because they were tested twice. The second assessment in the ABA schedule allowed us to determine whether the experimental treatment might produce a long-lasting effect.

The two kinds of assessment schedule were assigned to two groups of participants of equal size, matched on their disability level as determined by the Gross Motor Function Classification System (GMFCS).  

**Participants**

Inclusion criteria for participants in the study were (a) a diagnosis of spastic CP, (b) age between 3 and 7 yrs old, (c) ability to follow instructions, (d) Gross Motor Function Classification System rating of I–III, and (e) no surgical treatment during the preceding 6 mos before study onset. Twenty children were screened and 12 children met the inclu-
sion criteria, but only eight children joined the study program. All of the participants were diagnosed with spastic diplegic CP, with ages ranging from 3.5 to 6.3 yrs old. Two children were at level II motor function according to the Gross Motor Function Classification System, which indicated that they were able to walk without devices. Six children were at level III. They were moderately impaired and needed devices to ambulate (Table 1).

Equipment

Treadmill and Suspension System

A commercial treadmill (Trackmaster TM210AC) was used for gait training in this study. The treadmill started at 0.0 mph and gradually increased speed in increments of 0.1 mph. Suspension was achieved with LiteGait (LiteGait, Scottsdale, AZ). This system consisted of several parts, including a yoke, overhead straps, an adjustable harness, a base, and an actuator. A harness was provided to subjects for weight suspension and safety during gait training.

GAITRite Electronic Walkway System

The system (GAITRite, CIR. Systems, Inc. Clifton, NJ) contains an electronic walkway, a network controller, and software. The walkway is a 4.6-m-long, 0.9-m-wide, commercially available electronic walkway; it contains 13,824 sensors distributed in a 3.6-m-long, 0.6-m-wide, active area. The system outputs are temporal-distance gait parameters, such as velocity, cadence, stride length, and others. Excellent reliability of the quantification of temporal-distance gait parameters (intraclass correlation coefficient between 0.82 and 0.92) was reported.\(^{20,21}\) A high concurrent validity has also been demonstrated in reference to a clinical stride analyzer and the Vicon Motion Analysis System.\(^{20,22}\)

Treatment Program

TBWS

TBWS was administered on a treadmill and was supported in a LiteGait suspension system. The amount of body weight of suspension was determined by clinical judgment. The weight was monitored to be sufficient to avoid knee collapse during the single-limb support phase and to not hinder the swing leg from contacting the floor with the heel first.\(^{18}\) For the children with Gross Motor Function class II, the suspension weight needed was minimal, just for the purpose of safety. Treadmill speed was adjusted to a comfortable level for each child and was gradually increased with the improvement of child’s control. Children were encouraged not to hold the rail, and they freely moved their arms during gait training. One independent therapist (T.H.) facilitated and corrected the gait pattern of the child while the child was walking on the treadmill. The treatment time was 20 min/session, 2–3 sessions/ wk, for a total of 12 wks, in addition to their regular therapeutic exercise program.

Regular Therapeutic Treatment

The regular therapeutic treatment was individually planned according to the child’s needs, according to the philosophy of NDT. The treatment program was set to meet each child’s motor function status before entering the study program. The goals of the program were to normalize muscle tone, maintain or increase the joint range of motion, increase muscle strength, and improve motor function. The program was 2–3 times/wk, 30 min/session, and comprised mat exercises of range of motion, stretching, strengthening, and motor function activities. Gross motor activities included changing positions, lie to sit, sit to stand, and standing. Movement patterns were of concern, and exercise was not to induce or exaggerate the abnormal movement pattern.

Outcomes Measurement

The outcome measures included muscle tone, selective motor control, gross motor function, and temporal-distance parameters of gait. Muscle tone was measured with the modified Ashworth scale.\(^{23}\) Selective motor control was measured with the

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age, mos</th>
<th>Gender</th>
<th>Weight, kg</th>
<th>Height, cm</th>
<th>Diagnosis</th>
<th>Gross Motor Function Classification System</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAB1(^a)</td>
<td>65</td>
<td>Female</td>
<td>17.5</td>
<td>111</td>
<td>Spastic diplegia</td>
<td>III</td>
</tr>
<tr>
<td>AAB2</td>
<td>47</td>
<td>Female</td>
<td>14</td>
<td>103</td>
<td>Spastic diplegia</td>
<td>II</td>
</tr>
<tr>
<td>AAB3</td>
<td>75</td>
<td>Male</td>
<td>18.5</td>
<td>110</td>
<td>Spastic diplegia</td>
<td>III</td>
</tr>
<tr>
<td>AAB4</td>
<td>41</td>
<td>Male</td>
<td>14</td>
<td>92</td>
<td>Spastic diplegia</td>
<td>III</td>
</tr>
<tr>
<td>ABA1</td>
<td>41</td>
<td>Male</td>
<td>12</td>
<td>89</td>
<td>Spastic diplegia</td>
<td>III</td>
</tr>
<tr>
<td>ABA2</td>
<td>44</td>
<td>Male</td>
<td>13.8</td>
<td>98</td>
<td>Spastic diplegia</td>
<td>II</td>
</tr>
<tr>
<td>ABA3</td>
<td>61</td>
<td>Male</td>
<td>16.2</td>
<td>100</td>
<td>Spastic diplegia</td>
<td>III</td>
</tr>
<tr>
<td>ABA4</td>
<td>54</td>
<td>Male</td>
<td>15</td>
<td>96</td>
<td>Spastic diplegia</td>
<td>III</td>
</tr>
</tbody>
</table>

\(^a\) The child dropped out of the program before the third assessment of the program.
subject sitting on the floor, with hips flexed and knees comfortably extended, and with the subject able to see his or her feet. The subject was asked to dorsiflex each foot individually to a target. If the subject was able to dorsiflex his or her ankle without hip and knee flexion, a grade of 4 would be given; if ankle dorsiflexion was achieved mainly using tibialis anterior, but accompanied by hip and/or knee flexion, a grade of 3 was scored; if dorsiflexion was achieved using toe extensor muscles and some tibialis anterior, a grade of 2 was scored; if limited dorsiflexion was achieved mainly using toe extensor muscles, a grade of 1 was given; and a grade of 0 was given when there was no movement of ankle dorsiflexion. Gross motor function was measured with the Gross Motor Function Measure (GMFM). The GMFM is a criterion-referenced evaluation tool designed specifically for children with CP. The GMFM is composed of 88 test items, categorized into five developmental dimensions: dimensions A (lie/roll), B (sit), C (crawl/kneel), D (stand), and E (walk/run/jump). Each item is scored on a four-point rating scale. Item scores for each dimension are summed together and converted, yielding a percentage score for that dimension. The average of the percentage scores for all five dimensions yields a total score. Results of studies have provided support for the high internal reliability and construct validity of measurement of changes in motor function. The test–retest reliability and inter-rater reliability of the GMFM was also established with intraclass correlation coefficients between 0.7 and 1.0. Therefore, GMFM was chosen as the outcome measure assessment tool for the study.

The temporal-distance gait parameters measured with the GAITRite electronic walkway included gait velocity, stride length, cadence, and double-limb support time as a percentage of gait cycle. According to the GAITRite operating manual, the velocity was obtained by dividing the distance by the ambulation time; it was expressed in centimeters per second. The stride length was defined and measured on the line of progression between the heel points of two consecutive footfalls of the same foot; it was expressed in centimeters. The cadence was the numbers of footfalls in a minute. One independent therapist took all the measurements and was not involved in therapy; this therapist was not aware of any child's grouping or stage within the study. The study was approved by and followed the guidelines of the institutional review board of National Cheng Kung University Hospital.

Data Analysis

Statistical Analytic System (SAS) version 9.1 for Windows was used for data analysis. Because the sample size of the study was small, and the dependent variable was a percentage score, the multivariate analysis of variance was not appropriate. Therefore, we adopted the following analytic strategy, as reported in our previous paper on the effect of horse riding on children with CP. First, we decided that the primary analysis should be the one that compared the children's performances under the regular treatment and under the experimental treatment. To increase power, we needed to pool the data from the group that received the AAB schedule and the group that received the ABA schedule. This means the second and the third assessments of the AAB schedule and the first and the second assessments of the ABA schedule. But, before we did that, we had to establish that there was no effect of simply taking a test twice. Therefore, the first analysis that we did was a comparison of the performance between the first and second assessments for the children who received the AAB schedule. Because the results of the first analysis showed no signs of a test-taking effect (see the Results section), we conducted the primary analysis by pooling the data as described above.

We also added a third analysis that examined the difference between the second and third assessments in the ABA schedule. This analysis would inform us whether a potential experimental treatment effect could be sustained after the treatment had discontinued. The level of statistical significance was set at 0.05 for all the analyses.

RESULTS

Effect on Temporal Distance of Gait Parameters

Table 2 presents the group means, standard deviations, and ranges of gait velocity, stride length, cadence, and double-limb support percentage of gait cycle for the two groups at three assessments. Our first step analysis revealed no significant difference in any of the gait parameters between the first two assessments for children receiving the AAB schedule. These results allowed us to proceed with our primary analysis. The results of the primary analysis revealed a significant effect of the experimental treatment (i.e., TBWS plus regular therapy) on the stride length ($P = 10.34, P = 0.0236$) and a marginal, significant effect on double-limb support percentage of gait cycle ($P = 6, P = 0.058$) (Fig. 1). No significant change of velocity or cadence was noted. Finally, our third analysis revealed no significant difference in any of the gait parameters between the second and the third assessments for children receiving the ABA schedule.

Effect on Dimension Score of GMFM

Table 3 displays the means, standard deviations, and ranges of the dimension scores, and the
The total score of the GMFM measurement for the two groups at each assessment. At study entry, the children had an average score of 86.8 or 90.5 on dimension A, and 84.8 or 86.3 on dimension B. The scores were nearly full scores. Therefore, a ceiling effect of dimensions A and B could be expected.

Our first step analysis revealed no significant difference in any of the dimension scores or the total score of GMFM between the first two assessments for children receiving the AAB schedule. Therefore, we proceeded with our primary analysis. The primary analysis revealed a significant effect of the experimental treatment on the GMFM total score \( F = 52.74, P = 0.0008 \) as well as on dimension D score \( F = 8.4, P = 0.0338 \) and on dimension E scores \( F = 10.62, P = 0.0225 \) (Fig. 2). Our third analysis found no significant differences in any of the GMFM scores between the second and the third assessments for children receiving the ABA schedule.

**Effect on Muscle Tone, and Selective Motor Control**

The results of the three-step analysis of muscle tone and selective motor control showed that there

<table>
<thead>
<tr>
<th>TABLE 2 The group means, SD, and ranges of temporal distance gait parameters of two groups at three measurement times</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group AAB</strong></td>
</tr>
<tr>
<td>Mean ± SD</td>
</tr>
<tr>
<td><strong>Velocity, cm/s</strong></td>
</tr>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T2</td>
</tr>
<tr>
<td>T3</td>
</tr>
<tr>
<td><strong>Cadence, steps/min</strong></td>
</tr>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T2</td>
</tr>
<tr>
<td>T3</td>
</tr>
<tr>
<td><strong>Stride length, cm</strong></td>
</tr>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T2</td>
</tr>
<tr>
<td>T3</td>
</tr>
<tr>
<td><strong>DLS (%)</strong></td>
</tr>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T2</td>
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<td>T3</td>
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</table>

DLS, double-limb-support time as a percentage of gait cycle.

![FIGURE 1](attachment:image.png)  
**FIGURE 1** Comparison of the treatment effect of TBWS and regular therapeutic treatment on the gait parameters. TBWS, treadmill training with body weight support; regular, regular therapeutic treatment; DLS, double-limb support percentage of gait cycle. * \( P < 0.05 \); § \( P = 0.058 \).
was no effect of testing taking in children receiving the AAB schedule, no effect of the experimental treatment, and no difference between the second and the third assessments in children receiving the ABA schedule. In addition, there was no significant correlation between the change in GMFM or gait parameter and the change in muscle tone or selective motor control.

**DISCUSSION**

Using a task-oriented approach, this study examined the effect of TBWS gait training on gait performance and gross motor function in children with spastic CP. The results show that TBWS gait training for 12 wks helped to increase stride length and decrease the double-limb support percentage.
of gait cycle. The training also improved the children’s gross motor function, as manifested in their GMFM dimension D and E scores and their total scores.

Deficiencies in gait of children with spastic CP is one of their parents’ major concerns. Gait of children with CP is characterized with slow velocity, short stride length, and poor balance (increase of double-limb support percentage of gait cycle).31 At the baseline evaluation, our subjects showed slow walking velocity (average, 27.05 cm/sec) and a short stride length (average, 37.64 cm). These numbers were much smaller than those reported in normal children of a comparable age,32 but they were similar to those for children with spastic CP at a comparable age level and functional level.31 After 12 wks of TBWS gait training, children with spastic CP showed a significant increase in stride length and decrease in double-limb support percentage of gait cycle. Although the change in gait velocity did not reach the conventional level of statistical significance, it was in the direction of improvement.

Children with spastic CP also displayed improvement in GMFM dimension D (standing) and E (walk) scores and total score. Further, the effect of TBWS gait training on GMFM dimension D and E scores and total score seemed to be sustained for at least 12 wks, as demonstrated by a lack of statistically significant difference in group ABA participants between the second and the third measurements, when the participants had returned to their regular therapy programs. The results of our study are partly consistent with the findings of previous studies.15, 16 In Richards et al.’s15 study, young children with spastic CP (age range: 1.7–2.3 yrs) showed improvements in GMFM dimension scores of D and E after 4 mos of a combination of the conventional therapy and treadmill training. Schindl and colleagues16 also noted an improvement in the GMFM dimension D and E scores in children with either severely involved nonambulatory CP or mildly involved independently ambulatory CP after 3 mos of TBWS gait training.16

GMFM scores reflect a subject’s complex movement patterns that incorporate trunk strength and mobility as well as coordination and balance. Test items of dimensions A, B, and C are typically items involving mat activities, such as rolling, crawling, and transfer activities of sitting. Test items of dimensions D and E typically comprise upright activities such as standing and walking. Our regular therapeutic exercises contained some training activities in upright posture; however, they mostly consisted of therapeutic exercises on a mat. Therefore, from a task-oriented point of view, the effects of the regular therapeutic treatment on the GMFM dimensions D and E, if any, should be limited. The lack of significant changes of the scores of dimension A, B, and C were probably attributable to the subjects’ nearly full scores on those dimensions at the baseline.

The task-oriented approach emphasized that the training program should be specific and functional (meaningful) to the individual. Results of the previous studies have shown that both the content and the amount of therapy were important factors for improvement in the functional outcomes; the training effect was larger as the intensity of the program was increased.15, 33, 34 Our 12-wk study of TBWS gait training, with the assistance of a therapist’s sensory guidance for correct foot placement, allowed the children to perform a meaningful, functional task (walking) with multiple repetitions. The TBWS program in our study can be said to be quite intensive and lengthy, and the children, therefore, showed improvement.

The results of no significant effect of TBWS on muscle tone and selective motor control—neither a significant correlation of the change in gait performance or GMFM scores with muscle tone or selective motor control—were not surprising. This is probably attributable to the fact that muscle tone and selective motor control were measured under a static condition, and that gait and gross motor function are dynamic functions. Therefore, the muscle tone and the selective motor control may not be associated with walking performance or gross motor function.

Several limitations of the present study must be acknowledged. First, the sample size was small. Therefore, the power of the study to detect some smaller beneficial effects of training could be limited. The difficulty of recruiting children with CP to participate in such a lengthy study was the primary reason for the small sample. Most parents of children with CP were hesitant to let their children join a study that lasted 6 mos (24 wks). Second, the sample was a convenient one, like that of many other studies. Therefore, the generalization of the study must be limited. Third, the amount of body weight support and treadmill speed needed for training was determined individually according to the therapist’s clinical decision. Unfortunately, we did not keep a log of these data, and, therefore, we were unable to examine how they might affect the training effect. Nevertheless, this study, in accordance with previous ones, demonstrates that it is feasible to apply TBWS for gait training in children with spastic CP, and the results are encouraging.

CONCLUSIONS

Our study has demonstrated the effects of TBWS gait training on some gait parameters and gross motor function in children with spastic CP.
However, because of the small sample size of the present study, and the limited number of studies of this kind, a more definitive conclusion cannot be made until more findings are available.

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ABSTRACT

Objective: To assess the change in the balance performance and the improvement in the gait performance of subjects with hemiparesis, as a result of their wearing an ankle–foot orthosis.

Design: This was a cross-sectional control trial. Fifty-eight subjects with hemiparesis of a duration of less than 6 mos participated in this study. Each subject was evaluated for the balance and gait performance with and without an ankle–foot orthosis on the affected side. The balance activities were evaluated by the Balance Master System, and the gait performance was measured using GAITRite.

Results: The increase in movement velocity and the change in maximal excursion toward the affected side during the balance testing were found to be correlated significantly with the change in walking speed as a result of wearing an ankle–foot orthosis ($r = 0.274, P = 0.039; r = 0.325, P = 0.020$; respectively). Only the change in maximal excursion toward the affected side was found to be significantly correlated with the change in nonaffected step length ($r = 0.381, P = 0.010$).

Conclusion: The maximal excursion toward the affected side improved as a result of wearing an ankle–foot orthosis. This correlated with an increase in step length on the nonaffected side and, hence, an improvement in the walking speed of the subjects with hemiparesis.

Key Words: Ankle–Foot Orthosis, Balance, Gait, Hemiparesis
Attaining gait ability remains a challenge for hemiparetic patients. Considerable time and effort are required for ambulation training and orthotic management. The spatiotemporal gait parameters of hemiparetic patients are significantly different from those of healthy subjects. That is, the walking speed of hemiparetic patients is slower, the cadence is lower, their step length is shorter, and the stance phase of the uninvolved leg is longer.

Ankle-foot orthosis (AFO) is typically recommended to stroke patients to compensate for the effects of impairments to their walking and thus assist their rehabilitation following stroke. In particular, it is used in cases where there is inadequate dorsiflexion in swing and mediolateral subtalar instability during stance. Patients with hemiparesis are generally inefficient in the heel-strike and pushoff phases of their gait. Major AFO studies in the past on hemiparetic subjects emphasized the gait spatiotemporal, kinematic, and kinetic parameters. Gok et al. found that AFO changed the plateau pattern of curve to the usual double peak pattern in their six subjects, indicating better heel strike and more effective pushoff. They also observed an increase in ankle dorsiflexion at heel strike and midswing. Improvements in walking speed, gait pattern, and stride length have been documented. Franceschini et al. found that AFO significantly improved self-selected speed, stride cycle time, stance, and double-support time in their nine studied hemiparetic subjects, with postonset duration ranging from 2 to 244 mos. After a systematic literature review, Leung and Moseley suggest that AFO might improve the velocity, stride length, gait pattern, and walking efficiency of people with hemiplegia who could walk without an AFO.

It is also common for hemiparetic patients to suffer alterations in their postural stability or balance. Turnbull and associates found that even functionally ambulant hemiparetic patients demonstrated marked limitations in their capacity to shift weight, and possessed a reduced range of weight shift. The greater the weight the paretic limb was able to bear, the greater the distance the patient could shift the weight. Dettman and colleagues found a significant relationship between postural instability and walking performance. However, there have been few studies that have specifically addressed the effects of AFO on the balance dynamics of hemiparetic patients. Chen et al. found that AFO had significant effects on long-term hemiparetic patients with respect to lateral weight shifting and weight bearing through their affected side. In an earlier study, the present authors noted that after being provided with an AFO, patients with hemiparesis of recent onset experienced an increase in their gait speed and cadence, and an improvement in their dynamic standing balance. However, the effectiveness of wearing an AFO has been found to be minimal for patients with hemiparesis of long duration. Mojica et al. found that wearing an AFO significantly reduced body sway and increased the maximum walking speed of eight poststroke hemiparetic patients. But a clear correlation between the improvements in body sway and gait variables has not yet been established, because of small sample size and the heterogeneity of the patients. Therefore, the present study was aimed at assessing a large group of hemiparetic individuals within 6 mos poststroke for changes in the balance performance and improvement in the gait performance as a result of wearing AFOs.

METHODS

All subjects who participated in this study were referred from medical centers and district hospitals near the Taipei area in Taiwan. The diagnosis, age, sex, affected side, and onset time of hemiparesis were obtained from patient interviews and medical charts. Ankle muscle strength was evaluated using a handheld dynamometer (PowerTrack II; JTech Medical). All tests undertaken were isometric tests in which the dynamometer was held stationary by the examiner while each subject exerted a maximum force against it. The ankle dorsiflexor strength and ankle plantarflexor strength were obtained in the supine position. The lower-extremity function of all the subjects was evaluated using the Fugl–Meyer leg subscale, which included 17 items (the highest possible score was 34 points). The criteria for subject selection were as follows: 1) a diagnosis of unilateral hemiparesis secondary to a cerebrovascular accident, with symptoms having lasted less than 6 mos; 2) the ability to walk for 10 m without an assistive device; 3) never having worn an AFO before this study; 4) the ability to follow simple verbal commands or instructions; and 5) having no history of significant orthopedic problems that would interfere with gait and balance performance tested in our study. Fifty-eight subjects participated in this study, and all gave their informed consent before participation. All procedures performed in this study were approved by the human subject review board of Taipei Veterans General Hospital.

Each subject performed all measurement tests within 2 hrs. The tests were carried out both with and without an AFO on the affected foot. There was a 5-min rest period between each test, and the testing sequences were randomized. The AFO used in this study was a standard, posterior leaf type weighing 125 g, with a setting in neutral position. The orthosis came in three different sizes, and each
subject wore the size that fitted them best. Before measurement, the subjects took a short time to familiarize themselves with their newly prescribed AFO.

**Measurement of Standing Balance**

The Balance Master System was used in the study to test standing balance.\(^{17,20,21}\) The difference of the weight-bearing distribution (%) between each leg was recorded while the subjects stood as still as possible. Limit of stability (LOS) testing was used to record the subjects’ dynamic balance—that is, their ability to control the movement (maximum excursion) and speed (movement velocity) of their center of gravity (COG) during tasks that required weight shifts toward different directions. During this assessment, the location of the patient’s COG was displayed on screen as a cursor. The patient controlled the cursor by weight shifting. To perform the assessment task, the patient needed to move quickly and precisely to make the cursor reach the target. Three directions— anterior, affected side, and nonaffected side—were included in the test. The subjects were instructed to stand with their arms at their sides and to not move their feet throughout the testing procedure. Movement velocity was the average speed in degrees per second of the rhythmic movement along the specified direction. Maximal excursion was measured as the distance of the movement toward the designated target, expressed as a percentage of maximum LOS distance.\(^{17}\)

**Assessment of Gait**

The GAITRite system (CIR System, Inc.) was used to measure the subjects’ gait performance.\(^{22,23}\) The validity and reliability of GAITRite system have been well established.\(^{22,23}\) The GAITRite system provided temporal (time) and spatial (distance) gait parameters via an electronic walkway connected to the serial port of a personal computer. The standard GAITRite walkway contained six sensor pads in a roll-up carpet with an active area 3.66 m long and 0.61 m wide. As the subject walked through the walkway, the sensors captured each footfall as a function of time and transferred the gathered information to a personal computer to process the raw data into footfall patterns. The computer computed the temporal and spatial gait parameters. The gait parameters included in our study were gait speed, cadence, cycle time, swing time, stance time, single-support time, double-support time, step length, stride length, and base width. Subjects were asked to walk three times through a 10-m hallway, at a comfortable speed, without any assistive device. The GAITRite walkway was placed in the middle of the 10-m hallway to eliminate the effect of acceleration or deceleration.

The paired t testing was used to compare the balance and gait performance between wearing and not wearing the AFO. The correlations between the changes in balance ability and in gait performance with the AFO were assessed by Pearson correlation coefficients. A level of \(P < 0.05\) was considered statistically significant. All statistical analyses were carried out with SPSS version 10.0 for Windows.

**RESULTS**

Fifty-eight subjects who met our selection criteria—44 males and 14 females—participated in this study. Among them, 34 had right hemiparesis, and 24 had left hemiparesis; 19 had sustained hemorrhagic strokes, and 39 had sustained infarctions. The mean age of the subjects was 60.36 ± 13.95 yrs (range: 26–84 yrs); the mean onset duration was 3.29 ± 1.17 mos (range: 1–6 mos); the mean dorsiflexor strength measurements (in pounds) on the patients’ affected and nonaffected sides were 26.72 ± 11.57 (range: 12.95–45.19) and 40.02 ± 7.24 (range: 32.71–47.39), respectively; the mean plantarflexor strength measurements on the affected and nonaffected sides were 39.64 ± 16.86 (range: 18.33–68.50) and 53.72 ± 13.53 (range: 28.00–82.27), respectively; and the mean Fugl-Meyer leg score was 25.12 ± 3.97 (range: 17–32).

Furthermore, because the testing sequences were randomized, we compared the demographic characteristics between the subjects who were first tested wearing the AFO and those who were first tested without wearing the AFO. There were no statistically significant differences between these groups for age, stroke onset, stroke type, gender, hemiparetic side, ankle muscle strength, or Fugl-Meyer leg score (Table 1).

Patients’ weight bearing was more evenly distributed when wearing the AFO than when not wearing the AFO. The weight-bearing differences were 12.12 ± 8.25 and 8.86 ± 9.31% for without AFO and with AFO, respectively \((P = 0.044)\). Table 2 shows the LOS test results for increase in movement velocity toward the affected \((3.39 ± 1.62\) deg/sec without AFO and 4.53 ± 1.48 deg/sec with AFO, \(P = 0.040\)) and toward the nonaffected side \((3.93 ± 2.20\) deg/sec without AFO and 5.64 ± 5.87 deg/sec with AFO, \(P = 0.012\)). Table 2 also documents the increase in maximal excursion toward the affected side \((68.70 ± 23.61%\) without AFO and 74.81 ± 20.46% with AFO, \(P = 0.046\)). The increases were significant as a result of wearing an AFO. The improvements in the patients’ weight distribution and dynamic standing balance were further confirmation of our previous study results.\(^{17}\) The mean comfortable speed increased from 62.83 ± 26.71 to 66.94 ± 29.47 cm/sec (mean of change: 4.45 ± 10.71 cm/sec, \(P = 0.006\)) after wearing an AFO (Table 3). Among the spatiotem-
poral parameters measured, the patients' step length (mean of change: 2.69 ± 5.87 cm, \( P = 0.010 \) for the affected side; mean of change: 1.98 ± 5.06 cm, \( P = 0.008 \) for the nonaffected side), stride length (mean of change: 4.87 ± 9.55 cm, \( P = 0.002 \)), and base width (mean of change: 1.55 ± 3.55 cm, \( P = 0.002 \)) showed significant improvements after wearing an AFO (Table 3). Other gait parameters did not change significantly (Table 3).

The change in the patients' movement velocity and maximal excursion toward the affected side were found to correlate significantly with the change in walking speed as a result of wearing an AFO (\( r = 0.274, P = 0.039; r = 0.325, P = 0.020 \); respectively) (Table 4). However, only the change in maximal excursion toward the affected side correlated significantly with the change in step length of the nonaffected side (\( r = 0.381, P = 0.010 \) and the change in stride length (\( r = 0.360, P = 0.012 \) (Table 4). Also, the change in weight distribution was found to correlate negatively with the change in step length of the affected side (\( r = -0.325, P = 0.015 \) and the change in stride length (\( r = -0.264, P = 0.026 \) (Table 4).

**DISCUSSION**

In the present study, we found that the increase in hemiparetic patients' walking speed when wearing an AFO was correlated significantly with an improve-

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**TABLE 1** Comparisons of balance performance between wearing and not wearing ankle–foot orthosis (AFO) in subjects with hemiparesis (n = 58)

<table>
<thead>
<tr>
<th></th>
<th>Without AFO First (n = 29)</th>
<th>With AFO First (n = 29)</th>
<th>Changes</th>
<th>P Value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>60.38 ± 12.59 (30–84)</td>
<td>60.34 ± 15.41 (26–81)</td>
<td>-0.026</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Months after stroke</td>
<td>3.24 ± 1.35 (1–6)</td>
<td>3.34 ± 0.97 (2–6)</td>
<td>0.1</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>24 (82.76%)</td>
<td>20 (68.97%)</td>
<td>0.06</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>5 (17.24%)</td>
<td>9 (31.03%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemiplegic side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>16 (55.17%)</td>
<td>18 (62.07%)</td>
<td>0.12</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>13 (44.83%)</td>
<td>11 (37.93%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infarction</td>
<td>18 (62.07%)</td>
<td>21 (72.41%)</td>
<td>0.13</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>11 (37.93%)</td>
<td>8 (27.59%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle strength, pounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected dorsiflexors</td>
<td>25.98 ± 11.14 (14.10–38.84)</td>
<td>27.45 ± 12.98 (12.95–45.19)</td>
<td>0.32</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>Nonaffected dorsiflexors</td>
<td>41.4 ± 6.52 (36.82–47.39)</td>
<td>38.65 ± 8.68 (32.71–46.75)</td>
<td>0.17</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>Affected plantarflexors</td>
<td>40.01 ± 15.63 (18.33–51.50)</td>
<td>39.35 ± 18.52 (21.33–68.50)</td>
<td>0.12</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Nonaffected plantarflexors</td>
<td>55.94 ± 10.62 (33.33–66.50)</td>
<td>51.49 ± 17.42 (28.00–82.27)</td>
<td>0.24</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Fugl–Meyer leg score</td>
<td>25.41 ± 3.81 (18–32)</td>
<td>24.83 ± 4.16 (17–32)</td>
<td>0.07</td>
<td>0.58</td>
<td></td>
</tr>
</tbody>
</table>

Data were expressed as mean ± SD (range) or frequency (percentage).

---

**TABLE 2** Comparisons of balance performance between wearing and not wearing ankle–foot orthosis (AFO) in subjects with hemiparesis (n = 58)

<table>
<thead>
<tr>
<th></th>
<th>Without AFO</th>
<th>With AFO</th>
<th>Changes</th>
<th>P Value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight-bearing difference, %</td>
<td>12.12 ± 8.25</td>
<td>8.86 ± 9.31</td>
<td>-3.26 ± 4.43</td>
<td>0.044*</td>
<td>-3.863, -0.660</td>
</tr>
<tr>
<td>Movement velocity, deg/sec</td>
<td>2.53 ± 1.44</td>
<td>2.66 ± 1.19</td>
<td>0.13 ± 1.41</td>
<td>0.498</td>
<td>-0.506, 0.249</td>
</tr>
<tr>
<td>Anterior</td>
<td>3.39 ± 1.62</td>
<td>4.53 ± 1.48</td>
<td>1.14 ± 1.61</td>
<td>0.040*</td>
<td>0.060, 1.199</td>
</tr>
<tr>
<td>Affected</td>
<td>3.93 ± 2.20</td>
<td>5.64 ± 5.87</td>
<td>1.71 ± 6.22</td>
<td>0.012*</td>
<td>0.482, 2.418</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>64.88 ± 20.72</td>
<td>68.20 ± 18.41</td>
<td>3.32 ± 17.19</td>
<td>0.180</td>
<td>-10.926, 1.171</td>
</tr>
<tr>
<td>Maximal excursion (%)</td>
<td>68.70 ± 23.61</td>
<td>74.81 ± 20.46</td>
<td>6.11 ± 14.20</td>
<td>0.046*</td>
<td>-5.873, -1.663</td>
</tr>
<tr>
<td>Anterior</td>
<td>78.70 ± 19.52</td>
<td>78.84 ± 21.58</td>
<td>0.14 ± 18.58</td>
<td>0.955</td>
<td>-4.790, 5.070</td>
</tr>
<tr>
<td>Affected</td>
<td>398.70 ± 19.52</td>
<td>398.84 ± 21.58</td>
<td>0.14 ± 18.58</td>
<td>0.955</td>
<td>-4.790, 5.070</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>398.70 ± 19.52</td>
<td>398.84 ± 21.58</td>
<td>0.14 ± 18.58</td>
<td>0.955</td>
<td>-4.790, 5.070</td>
</tr>
</tbody>
</table>

Data were expressed as mean ± SD.
Changes: with AFO − without AFO.
* \( P < 0.05 \) vs. without AFO.
Previous study by Mojica et al.,\textsuperscript{18} who have demonstrated the significant decrease in body sway and improved walking capacity.\textsuperscript{18} Because of the small sample size and heterogeneity of the patients, however, Mojica et al.\textsuperscript{18} could not obtain a clear correlation between the improvements in body sway and gait variables. In the present study, with a larger sample group, we demonstrated a clear, significant correla-

**TABLE 3** Comparisons of spatiotemporal gait parameters between wearing and not wearing ankle–foot orthosis (AFO) in subjects with hemiparesis ($n = 58$)

<table>
<thead>
<tr>
<th></th>
<th>Without AFO</th>
<th>With AFO</th>
<th>Changes</th>
<th>$P$ Value</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed, cm/sec</td>
<td>62.83 ± 26.71</td>
<td>66.94 ± 29.47</td>
<td>4.45 ± 10.71</td>
<td>0.006**</td>
<td>1.226, 6.977</td>
</tr>
<tr>
<td>Cadence</td>
<td>88.62 ± 19.06</td>
<td>90.31 ± 22.98</td>
<td>1.75 ± 13.97</td>
<td>0.357</td>
<td>−1.955, 5.331</td>
</tr>
<tr>
<td>Cycle time, secs</td>
<td>1.45 ± 0.49</td>
<td>1.45 ± 0.48</td>
<td>0.00 ± 0.18</td>
<td>0.962</td>
<td>−0.047, 0.045</td>
</tr>
<tr>
<td>Swing time, secs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>0.52 ± 0.15</td>
<td>0.53 ± 0.19</td>
<td>0.01 ± 0.08</td>
<td>0.355</td>
<td>−0.011, 0.030</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>0.39 ± 0.08</td>
<td>0.40 ± 0.10</td>
<td>0.02 ± 0.09</td>
<td>0.276</td>
<td>−0.011, 0.039</td>
</tr>
<tr>
<td>Stance time, secs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected side</td>
<td>0.93 ± 0.38</td>
<td>0.92 ± 0.34</td>
<td>−0.01 ± 0.17</td>
<td>0.620</td>
<td>−0.057, 0.035</td>
</tr>
<tr>
<td>Nonaffected side</td>
<td>1.06 ± 0.47</td>
<td>1.06 ± 0.49</td>
<td>−0.00 ± 0.17</td>
<td>0.874</td>
<td>−0.041, 0.048</td>
</tr>
<tr>
<td>Single-support time, secs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>0.39 ± 0.08</td>
<td>0.40 ± 0.10</td>
<td>0.02 ± 0.09</td>
<td>0.276</td>
<td>−0.011, 0.039</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>0.52 ± 0.15</td>
<td>0.53 ± 0.19</td>
<td>0.01 ± 0.08</td>
<td>0.355</td>
<td>−0.011, 0.030</td>
</tr>
<tr>
<td>Double- support time, secs</td>
<td>0.54 ± 0.36</td>
<td>0.53 ± 0.35</td>
<td>−0.01 ± 0.19</td>
<td>0.775</td>
<td>−0.057, 0.042</td>
</tr>
<tr>
<td>Step length, cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>42.29 ± 12.27</td>
<td>44.58 ± 13.19</td>
<td>2.69 ± 5.87</td>
<td>0.010*</td>
<td>0.571, 4.016</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>39.98 ± 12.08</td>
<td>41.82 ± 14.63</td>
<td>1.98 ± 5.06</td>
<td>0.008**</td>
<td>0.493, 3.186</td>
</tr>
<tr>
<td>Stride length, cm</td>
<td>82.53 ± 22.95</td>
<td>86.86 ± 26.47</td>
<td>4.87 ± 9.55</td>
<td>0.002***</td>
<td>1.616, 7.043</td>
</tr>
<tr>
<td>Base width, cm</td>
<td>15.45 ± 4.70</td>
<td>13.95 ± 4.97</td>
<td>−1.55 ± 3.55</td>
<td>0.002***</td>
<td>−2.428, −0.566</td>
</tr>
</tbody>
</table>

Data were expressed as mean ± SD.
Changes: with AFO − without AFO.
* $P < 0.05$; ** $P < 0.01$ ex. without AFO.

**TABLE 4** Correlations ($r$) between changes in balance performance and gait parameters, resulting from wearing the AFO in subjects with hemiparesis ($n = 58$)

<table>
<thead>
<tr>
<th>Correlations</th>
<th>Movement Velocity, deg/sec</th>
<th>Maximal Excursion, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight-Bearing Difference</td>
<td>Anterior</td>
</tr>
<tr>
<td>Speed, cm/sec</td>
<td>0.111</td>
<td>0.109</td>
</tr>
<tr>
<td>Cadence</td>
<td>0.061</td>
<td>0.107</td>
</tr>
<tr>
<td>Cycle time, secs</td>
<td>−0.007</td>
<td>0.198</td>
</tr>
<tr>
<td>Swing time, secs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>−0.102</td>
<td>−0.050</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>0.107</td>
<td>0.088</td>
</tr>
<tr>
<td>Stance time, secs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>0.063</td>
<td>−0.230</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>−0.090</td>
<td>0.146</td>
</tr>
<tr>
<td>Single-support time, secs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>0.107</td>
<td>0.088</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>−0.202</td>
<td>−0.050</td>
</tr>
<tr>
<td>Double-support time, secs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step length, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>−0.325*</td>
<td>−0.131</td>
</tr>
<tr>
<td>Nonaffected</td>
<td>−0.183</td>
<td>−0.052</td>
</tr>
<tr>
<td>Stride length, cm</td>
<td>−0.264*</td>
<td>0.076</td>
</tr>
<tr>
<td>Base width, cm</td>
<td>0.189</td>
<td>0.006</td>
</tr>
</tbody>
</table>

* $P < 0.05$. 

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tion between the improvement in hemiparetic patients' dynamic balance control and an increase in their walking speed when using AFO.

Previous studies have indicated that stroke patients showed excessive postural sway and inadequate weight-shifting capacity in the frontal plane. It has been suggested that patients' frontal plane balance is particularly responsive to balance training and recovery. Chen et al. found that the use of AFOs by hemiparetic patients had significant effects on lateral weight shifting and weight bearing through their affected side. The greater the weight borne by the affected leg, the greater the range the subject could shift the weight to allow the opposite leg to move forward and, consequently, to take a step. According to present and previous studies, the use of AFO has shown significant effects on weight bearing during quiet standing, and in movement velocity during the LOS test toward both the affected and the nonaffected side, and maximal excursion toward the affected side. In the present study, we further documented that the change in maximal excursion toward the affected side correlated significantly with the change in step length of the nonaffected side ($r = 0.381, P = 0.010$) and walking speed ($r = 0.325, P = 0.020$) when wearing an AFO. Sackley and Lincoln demonstrated that improved stance symmetry was associated with superior ability to perform functional tasks. Walker et al. further found that, in addition to balance improvement, hemiparetic patients' walking speed was faster after balance training. It is thus suggested that improvement in weight bearing and in maximal excursion on the affected side, as a consequence of wearing AFO, contributes to the increase in step length on the nonaffected side and, hence, an improvement in walking speed. In the present study, in addition to improved maximal excursion toward the affected side, we also have noted that patients' movement velocity increased toward the affected and nonaffected side when wearing the AFO. The effect of improved movement velocity with respect to gait velocity was more significant toward the affected side ($r = 0.274, P < 0.05$) than toward the nonaffected side ($r = 0.142$, NS). According to these findings, we speculate that the improvement in walking speed is attributable to the improved balance control in the affected side that occurs as a result of wearing an AFO.

The improvement in our study in patients' walking speed was not, as expected, attributable to the improved maximal excursion range in the anterior direction. The maximal excursion in the forward direction was not changed significantly after wearing an AFO. The test of maximal excursion in the forward direction was within the inverted pendulum model of the upright stance. The limitations in the anterior–posterior movement of the ankle joint, because of the wearing of an AFO, may have resulted in it having a minimal effect on the maximal balance range in the forward direction. However, the patients' ability for forward weight shifting, as indicated by the forward maximal excursion in our study group, was $64.88 \pm 20.72\%$ without an AFO and $68.20 \pm 18.41\%$ with one; this was significantly less than the forward maximal excursion for normal, similar-aged adults ($88.79 \pm 17.91\%$; mean age, $71.9 \pm 6.7$ yr old) that we reported in our other related study (Wang et al., unpublished data, 2005). It is important for clinicians to take note of the insufficient control over anterior weight shifting and the limitations of AFOs on their forward movement control in subjects with hemiparesis.

The results of this study reveal a statistically significant improvement in the hemiparetic patients' dynamic balance control and walking speed when wearing an AFO. However, given the small percentage of the increase in walking speed, it is noteworthy that, despite the clear statistical significance, the clinical significance of AFOs in gait performance might remain limited.

We also have noted that the step length of the patients' affected side increased and the base width decreased during walking when they were wearing AFOs, even though neither factors significantly affected walking speed. Ankle dorsiflexion at heel strike and at midswing has been shown to increase when patients have donned the plastic AFO. The increased ankle dorsiflexion at midswing may result in an increased step length. The decreased base width during walking may further support the improvement of dynamic balance control during the wearing of an AFO.

In our study, AFOs affected spatial parameters (step length and stride length) but not temporal parameters. Franceschini et al. and Churchill et al. have already documented the improvement in temporal parameters during walking while wearing an AFO. On examining the characteristics of our subjects and the characteristics of these previous study subjects, we noted that the walking speed of our subjects ($66.9 \pm 29.4$ cm/sec) was faster than that of their subjects ($31 \pm 2.0$ cm/sec for Churchill et al.'s subjects, and $25.8 \pm 11.5$ cm/sec for Franceschini et al.'s subjects). According to the study by Perry et al. on the classification of walking handicaps in stroke populations, the walking ability of our subjects fell into the functional walking category of least-limited community ($58 \pm 18$ cm/sec), whereas Churchill et al.'s and Franceschini et al.'s subjects were categorized as limited household ($23 \pm 16$ cm/sec) or unlimited household ($26 \pm 11$ cm/sec) ambulators. Further research is needed to investigate...
the effect of the AFO on subjects with different walking abilities or speed.

In summary, for subjects with hemiparesis of less than 6-mo duration and with a relatively fast walking speed, wearing an AFO can still improve gait speed. We found that this improvement correlated significantly with the dynamic balance control of the patients' affected side. The results of our previous study have shown that wearing an AFO had a minimal effect on subjects with long-duration (>12 mos) hemiparesis. Therefore, it may be beneficial to prescribe an AFO to patients in the early stage, rather than the late stage, of stroke recovery. Patients wearing an AFO could improve their dynamic balance control and, thus, increase their walking speed. Furthermore, it is suggested that AFOs may play an important role in the functional improvement of hemiparetic stroke patients. Use of AFOs at discharge has been associated with the walking and stairs component of the FIM instrument and the Berg balance scale score. The present study has only investigated the immediate effects of using an AFO. It is possible that more sustained use of an AFO would affect these parameters as well; further studies are needed to examine this possibility.

REFERENCES
Predicting Discharge of Trauma Survivors to Rehabilitation
A Sampling Frame Solution for a Population-Based Trauma-Rehabilitation Survey

ABSTRACT


Objectives: To conduct a population-based survey among trauma survivors on accessibility to rehabilitation services in metropolitan, urban, and rural areas in Quebec (Canada), we attempted to use trauma registries as a sampling frame of subjects discharged to rehabilitation. Discharge destinations were inaccurate in many registries, preventing straightforward identification of the survey subjects. Using the best registry data, we aimed to identify predictors of rehabilitation discharge and to use them to specify a reliable sampling frame for the survey.

Design: A logistic predictive model of rehabilitation discharge was developed. This model was applied to data from metropolitan, urban, and rural trauma centers to identify all subjects predicted to be discharged to a rehabilitation facility.

Results: Age, acute-care length of stay, injury-severity score, lower-limb injuries, and seven other predictors were included in the model that generated an area under the ROC curve (AUC) of 0.83 and a classification accuracy of 76.6%. The metropolitan, urban, and rural frames were slightly different. They included, respectively, 808, 798, and 929 subjects.

Conclusions: The procedure helped us bypass largely inaccurate data from trauma registries. The sampling frames reflected severely injured trauma survivors who were likely to have been referred to postacute rehabilitation.

Key Words: Prediction, Rehabilitation, Trauma, Sampling Method
Various barriers to accessing appropriate and timely rehabilitation services for individuals with disabilities have been identified recently in the United States, Australia, and Canada. However, the effects on the health status of people who require those services have rarely been studied. In the province of Quebec, Canada, numerous difficulties in accessing rehabilitation services, as well as an undersupply of general and specialized rehabilitation resources, have been identified by health administrators and researchers in many regions.

In an attempt to measure accessibility to a large range of rehabilitation services, and its impact on the health status of trauma survivors, a large survey was conducted across metropolitan, urban, and rural areas of the province of Quebec. This paper presents the analytical method used to specify the sampling frame for this study.

It is well known that cost-effective drawing of any unbiased sample from a target population, with response rates high enough to answer a research question, is far from trivial. Sampling trauma survivors discharged to rehabilitation across the province of Quebec, through various means, in a large number of facilities such as rehabilitation centers and clinics, nursing homes, and community organizations, would have been prohibitive in cost and time for a probable low response rate. Beatty et al. have recently illustrated their difficulties in sampling people with disabilities through a similar approach in the United States.

The Quebec Trauma Registry (QTR) was thought to offer an ideal, readily available pool of study subjects. Indeed, the QTR is the mandatory provincial clinical–administrative database for each of the 59 designated level I, II, and III trauma centers across the province; it contains prospectively collected information on traumatic events, injury severity, treatments received, and discharge destination from acute care. Such trauma registries have been used for more than two decades to evaluate the effectiveness of prehospital and acute-care trauma systems in the United States and Canada, but these registries are rarely employed in rehabilitation research. The QTR list of trauma survivors discharged to rehabilitation settings in the province seemed to constitute an ideal sampling frame for our survey and a natural and timely extension toward rehabilitation research of the QTR.

Coding variability and missing data are common in large trauma registries, mostly for prehospital and emergency room data. Some specific discrepancies in the coding and interpretation of discharge destinations have also been described. The QTR is no exception. Indeed, the data show important variations (1–40%) in the proportion of trauma survivors discharged to rehabilitation in 2000–2001 from level I and II trauma centers. Verifications with registrars from urban and rural level II trauma centers (there are no level I trauma centers in Quebec) revealed important miscoding of their discharge destination variable. Indeed, large proportions of their patients requiring postacute rehabilitation were actually coded as discharged to acute care or home. The QTR variable discharge to rehabilitation was thus invalid for an unquantifiable, but presumably large, number of patients treated in many urban and rural level II trauma centers. Clearly, using the list of discharges to rehabilitation from those centers would have led to severe undersampling of trauma survivors in those areas.

To specify the sampling frame, we aimed to identify the predictors of rehabilitation discharge in trauma survivors using data from trauma centers that provided standardized, valid information on discharge destinations in the QTR. These predictors would then be used to identify all potential subjects for the survey.

The literature is rather scarce on who, among trauma survivors, are discharged to rehabilitation. Expert opinions and quantitative studies converge on the identification of a few medical and nonmedical predictors of rehabilitation discharge. Above all, diagnosis and severity of injuries are the most important factors. In their traumatic brain injury (TBI) sample, Wagner et al. found the injury-severity score (ISS) and the revised trauma score (RTS) to be significant predictors of rehabilitation vs. home discharge. In that study, patients were 0.875 times as likely to be discharged home for each unit increase in ISS and 1.271 times for each unit increase in RTS. Regardless of diagnoses, Emhoff et al., in their study of 109 multi-trauma patients, found significant differences in discharge FIM scores among patients who were discharged home (108/126) and those who went to a rehabilitation facility (52/126). In multiple-regression analyses conducted on a subset of TBI patients, Wrigley et al. found acute-care length of stay (ALOS), age, and the presence of complications to be significantly associated with referral to rehabilitation. Among nonmedical factors, type of healthcare insurance is considered by many authors to be a potential source of disparities in discharge destinations after acute care in the United States. Chan et al. have shown that in a Washington State level I trauma center, Medicaid and HMO TBI patients had a higher adjusted relative risk of being discharged to a skilled nursing home vs. a rehabilitation facility compared with patients insured by fee-for-services plans. In the Wagner et al. study, Medicaid and Medicare were important predictors of discharge home vs. rehabilitation. In the province of Quebec, concerns...
have been raised about the fact that victims of motor vehicle crashes, all automatically covered by the Quebec Automobile Insurance Society (SAAQ), might benefit from a privileged access to rehabilitation services compared with other types of trauma victims who benefit from the general, less rewarding provincial health-coverage plan. Other nonmedical factors, such as the family’s willingness and ability to provide care and support, the marital status of the patient, and various health system organizational elements, have been identified as influencing TBI patients’ discharge destinations.

The objectives of this first phase of our provincial survey on access to rehabilitation services and its impact on trauma survivors’ health status were to 1) use the best registry data to identify predictors of rehabilitation discharge, 2) use these predictors to specify the sampling frames of subjects in metropolitan, urban, and rural areas, and 3) compare the sampling frames generated by this method.

**METHODS**

The methodology involved four steps: 1) identifying the most valid and standardized registry data, and pruning the data; 2) building the predictive model; 3) specifying the sampling frames in the three areas; and 4) comparing the sampling frames. Each step is described in detail below.

**Step 1: Identifying the Most Valid and Standardized Registry Data, and Pruning the Data**

The data used for model building had to fulfill two conditions. First, the data had to come from trauma centers located in areas where the availability of the rehabilitation resources would be sufficient for the patients to be discharged to them. Second, to rely with confidence on the discharge-destination information, the coding of that variable had to be valid and standardized across the trauma centers. The research and administrative information available indicates that in the late 1990s, the nonmetropolitan areas were, in fact, underserved in general and in specialized rehabilitation resources, and the availability of rehabilitation services was best in the two largest metropolitan areas of the province. Data from the two level I trauma centers located in Montreal and the one in Quebec City were thus selected. Moreover, these centers use full-time, seasoned QTR coders, and they offer the best homogeneity in discharge-destination interpretation and coding.

The QTR includes all trauma patients who died, were transferred to another hospital, were admitted to the intensive care unit, or were admitted for more than 2 days. A minimal core dataset is mandatory for all centers, and an extended dataset is mandatory only for the level I trauma centers. Given that a predictive model was to be built on the level I trauma center data, and that this model would later be applied to data from level II trauma centers, only the minimal core dataset could be considered.

The inclusion criteria applied to each dataset were to 1) 18 yrs or older, and 2) discharged alive from acute care. Trauma patients were excluded if they 1) discharged themselves against medical advice, 2) had a missing discharge destination, or 3) were discharged outside the province. The available data cover the time period from April 1, 1999 to March 31, 2001.

To constitute a meaningful, manageable database, all available information on demographics, injury-related variables, acute medical conditions, acute interventions, and nonmedical factors identified in the literature as potentially associated with rehabilitation discharge was kept in the datasets.

A preliminary dataset including 136 variables and 7782 patients was, thus, constituted for model building. Table 1 shows the characteristics of the subjects included in each dataset.

**Step 2: Building the Predictive Model**

**Predicted Variable (Outcome)**

There are 10 possible postacute destinations in the QTR: 1) home with help, 2) home without help, 3) transfer to another acute-care center, 4) long-term care hospital, 5) nursing home, 6) rehabilitation, 7) discharge against medical advice, 8) unknown destination, 9) awaiting rehabilitation services, and 10) other. Because the objective of the current study was to identify trauma survivors discharged to rehabilitation services among all other post–acute care issues, a dichotomous variable was created, with the categories rehabilitation and awaiting rehabilitation services in the discharged to rehabilitation group; all other categories fit into the no rehabilitation discharge group. It is to be noted that the QTR rehabilitation category does not differentiate between in- and outpatient rehabilitation services.

**Selecting Potential Predictors: Preliminary Analyses**

Preliminary bivariate analyses were performed for each variable to select the best potential predictors of rehabilitation discharge. Selection criteria for dichotomous variables were to present a 5% events (rehabilitation discharge) per variable and an area under the ROC curve larger than 0.50. AUC ranges from 0 to 1; an AUC of 0.50 is considered nondiscriminant. The closer AUC is to 1, the better the variable can classify the subjects.
who experience the outcome (rehabilitation discharge) and the subjects who do not. A number of bivariate analyses were performed with continuous variables to identify their best functional form (continuous vs. various categorizations), using the highest AUC as the criterion.

**Missing Data**

The RTS and the Glasgow coma scale, which are two important measures of injury severity, were found to present, respectively, 25% and 50% missing data. The RTS is a physiologic severity index derived from the patient’s initial systolic blood pressure, respiratory rate, and Glasgow coma scale. Missing RTS and Glasgow coma scale scores are reported to be up to 21% in mortality studies. Although some imputation methods are promising, excluding patients with missing RTS and Glasgow coma scale scores is still common, regardless of potential biases. We chose to remove these two variables rather than the patients, and to rely on other clinical variables for the prediction of rehabilitation discharge in trauma survivors.

**Injury-Related Variables**

Injury-related variables were derived from the 1990 revision of the Abbreviated Injury Scale (AIS) scoring system. The AIS describes the anatomic site and the nature and severity of each injury on an ordinal scale ranging from 1 (minor injury) to 6 (lethal injury). According to the AIS codes, dichotomous variables were created for each of the following anatomic locations of injury: head, face, cervical area, abdomen and thorax, thoracic spine, lumbar spine, pelvic area, and lower and upper limbs. Also derived from the AIS were the number of injuries (counts of AIS codes) and the number of injured body regions.

The ISS is a measure of anatomic severity of injury. It ranges from 1 to 75 and is defined as the sum of squares of the highest AIS severity scores in the three most severely injured body regions.

**TABLE 1**

Selected characteristics of the subjects, included in the different datasets

<table>
<thead>
<tr>
<th>Dataset Used for Model Building</th>
<th>Datasets Used for Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Level I Centers (Metropolitan) (n = 7782)</td>
<td>Two Level I Centers (Metropolitan) (n = 5531)</td>
</tr>
<tr>
<td>Discharges to rehabilitation according to the registries, n (%)</td>
<td>2243 (28.8)</td>
</tr>
<tr>
<td>Age, n (%)</td>
<td></td>
</tr>
<tr>
<td>18–55 yrs</td>
<td>3759 (48.3)</td>
</tr>
<tr>
<td>56–75 yrs</td>
<td>1761 (22.6)</td>
</tr>
<tr>
<td>≥76 yrs</td>
<td>2262 (29.1)</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>4304 (55.3)</td>
</tr>
<tr>
<td>Mechanism of injury, n (%)</td>
<td></td>
</tr>
<tr>
<td>Falls</td>
<td>4391 (56.4)</td>
</tr>
<tr>
<td>MVC</td>
<td>2213 (28.4)</td>
</tr>
<tr>
<td>Other</td>
<td>1178 (15.2)</td>
</tr>
<tr>
<td>ISS, n (%)</td>
<td></td>
</tr>
<tr>
<td>1–8</td>
<td>1941 (24.9)</td>
</tr>
<tr>
<td>9–15</td>
<td>3793 (48.7)</td>
</tr>
<tr>
<td>16–21</td>
<td>925 (11.9)</td>
</tr>
<tr>
<td>22–29</td>
<td>747 (9.6)</td>
</tr>
<tr>
<td>30–41</td>
<td>272 (3.5)</td>
</tr>
<tr>
<td>42–75</td>
<td>104 (1.3)</td>
</tr>
<tr>
<td>Head injuries, n (%)</td>
<td>2293 (29.5)</td>
</tr>
<tr>
<td>Spine injuries, n (%)</td>
<td>1112 (14.3)</td>
</tr>
<tr>
<td>Lower-limb injuries, n (%)</td>
<td>4136 (53.2)</td>
</tr>
<tr>
<td>Thoracic injuries, n (%)</td>
<td>1181 (15.2)</td>
</tr>
<tr>
<td>ALOS, days (mean ± SD)</td>
<td>13.2 ± 15.9</td>
</tr>
<tr>
<td>Assisted ventilation, n (%)</td>
<td>926 (11.9)</td>
</tr>
<tr>
<td>Acute-care complications, n (%)</td>
<td>2188 (28.1)</td>
</tr>
</tbody>
</table>

MVC, motor vehicle crash; ISS, injury-severity score; ALOS, acute-care length of stay.

* The trauma registries do not differentiate between in- and outpatient rehabilitation; invalid measure.

* Different at the P = 0.01 level.

121x333
Acute Care–Related Variables

Acute complication variables were created using the two QTR coding systems that account for medical complications during the acute-care phase. The first one includes 16 dichotomous (yes/no) variables describing the most common complications, such as pneumonia, cardiac failure, and urinary track infection. Others are coded with the ninth revision of the International Classification of Diseases.

Nonmedical Factors

Among the nonmedical factors possibly related to rehabilitation discharge, only the type of insurance coverage was available in the QTR.

At the end of the preliminary analysis, a total of 21 variables were identified as potential predictors of rehabilitation discharge in trauma survivors (Table 2).

Model Building: Main Analysis

The 21 preselected variables were considered in the “best subsets” automated selection of covariates methods, provided by the SAS PROC LOGISTIC module, to quickly screen a large number of potential models.\(^23\) Parsimonious models are generally recommended for numeric and clinical reasons.\(^23,29\) However, given the size of the dataset and the goal of the study, parsimony was not the most important aspect of the analyses. The AUC was systematically computed for the first five best models of each size—those containing 1 to 21 variables. The five best models (AUC \(\geq 0.83\)) were then submitted to a Monte Carlo cross-validation strategy to validate the models’ rates of classification accuracy.\(^30\) The SAS macro CVLR\(^30\) was used to perform 1000 resampling iterations with a proportion of 25% of the data in the validation sets. The most accurate model was selected as the final predictive model of rehabilitation discharge in trauma survivors. Interaction terms were then examined at the \(P \leq 0.01\) level. Regarding the predictive context of the analyses, confounding effects were not considered.

For the final model, the classification table that summarized the sensitivity, specificity, and proportion of subjects correctly classified for each level of probability of being discharged to rehabilitation (cut point) was generated. The cut point that both maximized the proportion of subjects correctly classified and minimized the proportion of subjects falsely classified as no rehabilitation discharge (false-negative) was selected. The selection was made regardless of the proportion of false-positive subjects generated by the logistic model. Indeed, we had the a priori clinical knowledge, from level I QTR coders and trauma team coordinators,

![Table 2](https://example.com/table2.png)

**Table 2** Variables preselected as potential predictors of discharge of trauma survivors to rehabilitation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best Functional Form</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>Three categories: ≤55, 56–75, 76+</td>
<td>0.62</td>
</tr>
<tr>
<td>Gender</td>
<td>n/a</td>
<td>0.55</td>
</tr>
<tr>
<td>Injury-related variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower-limb injuries</td>
<td>Yes/no</td>
<td>0.62</td>
</tr>
<tr>
<td>Brain injury</td>
<td>Yes/no</td>
<td>0.55</td>
</tr>
<tr>
<td>Injury to any spine level</td>
<td>Yes/no</td>
<td>0.53</td>
</tr>
<tr>
<td>Cervical spine injury</td>
<td>Yes/no</td>
<td>0.52</td>
</tr>
<tr>
<td>Thoracic injury</td>
<td>Yes/no</td>
<td>0.52</td>
</tr>
<tr>
<td>Number of injuries</td>
<td>Count (range 1–19)</td>
<td>0.58</td>
</tr>
<tr>
<td>Number of injured body regions</td>
<td>Count (range 1–8)</td>
<td>0.57</td>
</tr>
<tr>
<td>Injury mechanism</td>
<td>Categories</td>
<td>0.57</td>
</tr>
<tr>
<td>ISS</td>
<td>Categories: 1–8, 9–15, 16–21, 22–29, 30–41, 42–75</td>
<td>0.66</td>
</tr>
<tr>
<td>Acute care–related variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALOS, days</td>
<td>Categories: 1–3, 4–5, 10–13, 14–16, 17+</td>
<td>0.77</td>
</tr>
<tr>
<td>ICU stay</td>
<td>Yes/no</td>
<td>0.59</td>
</tr>
<tr>
<td>Any medical complication</td>
<td>Yes/no</td>
<td>0.64</td>
</tr>
<tr>
<td>Infectious complications</td>
<td>Yes/no</td>
<td>0.59</td>
</tr>
<tr>
<td>Circulatory/respiratory complications</td>
<td>Yes/no</td>
<td>0.55</td>
</tr>
<tr>
<td>Dermatologic/wounds complications</td>
<td>Yes/no</td>
<td>0.53</td>
</tr>
<tr>
<td>Change in mental state</td>
<td>Yes/no</td>
<td>0.54</td>
</tr>
<tr>
<td>Assisted ventilation</td>
<td>Yes/no</td>
<td>0.58</td>
</tr>
<tr>
<td>Nonmedical factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAAQ insurance</td>
<td>Yes/no</td>
<td>0.54</td>
</tr>
<tr>
<td>CSST insurance</td>
<td>Yes/no</td>
<td>0.52</td>
</tr>
</tbody>
</table>

AUC, area under the ROC curve; ISS, injury-severity score; ALOS, acute-care length of stay; ICU, intensive care unit; SAAQ, Quebec automobile insurance board; CSST, Quebec workmen’s compensation plan.
that an unknown number of trauma survivors admitted to level I trauma centers, who required rehabilitation services, remained misclassified. Those subjects were most frequently sent home as they awaited their admission to various rehabilitation settings. The best classification cut point was determined at 0.40. Thus, all subjects with a probability $\geq 0.40$ of being discharged to rehabilitation, according to the selected predictive model, were considered discharged to rehabilitation services.

**Step 3: Specification of the Sampling Frames in the Three Areas**

The selected predictive model with the 0.40 cut point was then applied to two metropolitan level I and eight urban or rural level II trauma centers’ data to determine the three sampling frames for the survey. Given the important unreliability of the outcome variable discharge destination from most level II trauma centers, the external validity of the predictive model could not be assessed using data from those centers.

**Step 4: Comparing the Sampling Frames**

The characteristics of the trauma survivors included in the metropolitan, urban, and rural sampling frames were compared to examine potential biases. ANOVA and the Scheffé test were conducted to test for significant differences in continuous variables among groups as defined by the metropolitan, urban, and rural frames. $\chi^2$ tests (exact procedure) were conducted to test for differences in categorical variables.

All statistical analyses were performed using version 8.2 of the SAS software.

**Ethical Considerations**

This study received approval from the Commission d'accès à l'information du Québec (Quebec Information Access Board) and from the research and ethic committees of each of the 11 trauma centers that provided data.

**RESULTS**

**Comparing the Datasets**

Table 1 presents selected characteristics of the 7782 trauma survivors included in the dataset used to build the predictive model, as well as the 13,882 subjects in the datasets used to identify the sampling frames. All subjects were adults discharged alive from the trauma centers between April 1, 1999 and March 31, 2001. Across the data, age ranged from 18.0–106.1 yrs. In model building, sampling level I, and sampling level II datasets, the mean age was respectively 56.3 ± 23.0, 57.4 ± 23.0, and 56.8 ± 22.8 yrs. Overall, a proportion of 72.0% of subjects suffered from two or more injuries, 24.0% had SAAQ insurance coverage, 7.0% had a workmen insurance coverage, and 64.2% were covered by the general Quebec public health-care plan. As shown in Table 1, significant differences at the $P = 0.01$ level were observed between level II and level I datasets. Subjects treated in level II trauma centers were generally less severely injured, with a mean ISS of 9.2 ± 6.1 vs. 12.1 ± 8.8 and 11.8 ± 8.9. The level II trauma survivors also presented fewer head and spinal injuries than their level I counterparts. The proportion of lower-limb injuries was almost 10% higher in level II data, and the proportion of assisted ventilation was almost 8% lower. Finally, the acute-care complications were more frequent in the model-building dataset than with the two sampling sets.

**Potential Predictors of Rehabilitation Discharge**

Overall, 21 variables were identified as potential predictors of rehabilitation discharge in trauma survivors. Table 2 shows those variables, their best functional form (dichotomous, categorical, or continuous), and their associated AUC. Figure 1 illustrates the proportions of trauma survivors discharged to rehabilitation according to the best discriminant form of the three strongest predictive variables taken independently: ALOS (AUC = 0.77), ISS (AUC = 0.66), and age (AUC = 0.62). These intermediate results are important because the role of these variables in the prediction of rehabilitation discharge in general trauma populations has not been strongly established yet.

**Predictive Model of Rehabilitation Discharge**

Table 3 shows the 11 variables included in the final predictive model of rehabilitation discharge, their estimated regression coefficients, and odds ratios with 95% confidence intervals. The general capacity of this model to discriminate trauma survivors discharged to rehabilitation from those who were not was excellent, with an AUC of 0.83. At the 0.40 cut point, the model had a specificity of 82.8% and a sensitivity of 61.5%. At that probability level, 76.6% of subjects were correctly classified when compared with their actual QTR discharge destinations. The model inappropriately classified 15.9% of subjects, for whom it predicted no rehabilitation discharge, and 40.9% of subjects, for whom a discharge to rehabilitation was predicted. In this predictive model, each unit increase in age, ISS, and ALOS categories (Fig. 1) increased the odds of being discharged to rehabilitation by 1.6, 1.7, and 1.8 times, respectively. The presence of lower-limb, spinal, and cervical injuries increased the odds of rehabilitation discharge by 3.0, 1.5, and 1.5 times.
respectively. Trauma survivors with SAAQ insurance coverage were somewhat less likely to require rehabilitation than those who were not insured by the SAAQ.

Comparing the Sampling Frames

The proportions of subjects for whom the model predicted a discharge to rehabilitation services were 28.8% in level I trauma centers and 20.9% in urban or rural level II trauma centers. From the 3314 trauma survivors who were identified by the model as discharged to rehabilitation, 2535 were eligible for the survey (admitted between January 1, 2000 and December 31, 2001). A total of 808 (31.8%) subjects were from metropolitan areas, 798 (31.5%) were from urban areas, and 929 (36.6%) from rural areas. Table 4 shows the characteristics of the identified subjects in each area. The three groups were significantly different in some of their characteristics. The rural group was slightly but significantly younger than the metropolitan one. The proportion of falls was higher, and the proportion of motor vehicle crashes was lower, among the metropolitan subjects than in the two other groups. Except for lower-limb injuries, which were more frequent in the rural sample, there were no other differences among the groups with regard to injured body regions. ALOS was shorter in the metropolitan sample than in the two other groups. Finally, the proportion of acute-care complications was much higher among the rural subjects.

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>Final predictive logistic model of discharge of trauma survivors to rehabilitation (n = 7782)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression Coefficient</td>
<td>Standard Error</td>
</tr>
<tr>
<td>Intercept</td>
<td>-4.36</td>
</tr>
<tr>
<td>ALOS</td>
<td>0.47</td>
</tr>
<tr>
<td>ISS</td>
<td>0.51</td>
</tr>
<tr>
<td>Age</td>
<td>0.56</td>
</tr>
<tr>
<td>Spinal injury</td>
<td>0.41</td>
</tr>
<tr>
<td>Assisted ventilation</td>
<td>0.47</td>
</tr>
<tr>
<td>Gender (male)</td>
<td>-0.23</td>
</tr>
<tr>
<td>SAAQ</td>
<td>-0.04</td>
</tr>
<tr>
<td>Acute-care complications</td>
<td>0.31</td>
</tr>
<tr>
<td>Thoracic injuries</td>
<td>-0.74</td>
</tr>
<tr>
<td>Lower-limb injuries</td>
<td>1.10</td>
</tr>
<tr>
<td>Cervical injuries</td>
<td>0.40</td>
</tr>
<tr>
<td>AUC = 0.83</td>
<td></td>
</tr>
<tr>
<td>Specificity = 82.8%; sensitivity = 61.5%; correct classification rate = 76.6%</td>
<td></td>
</tr>
</tbody>
</table>

ALOS, acute-care length of stay; ISS, injury-severity score; SAAQ, Quebec Automobile Insurance Society, AUC, area under the ROC curve.
DISCUSSION

The goal of this study was to use trauma registries to specify the sampling frames of trauma survivors discharged to postacute rehabilitation services in metropolitan, urban, and rural areas of the province of Quebec to further study their accessibility to rehabilitation services and their long-term health status. Because direct use of the discharge-destination information recorded in the QTR was impossible, we determined the sampling frames through 1) the development of a predictive logistic predictive model of rehabilitation discharge, using the best available data; and 2) the application of that model to data from two metropolitan level I and eight urban or rural level II trauma centers, to identify all potential survey subjects.

The differences observed between the level I and level II datasets used in this study (Table 1) are reflective of the Quebec trauma-care system, which is designed to admit, either directly or through transfers, the most severely injured patients to level I trauma centers. Indeed, the critically injured trauma patients first brought to level II centers who require brain and/or spine surgeries and other ultraspecialized acute care are actually transferred to level I trauma centers.

The multivariate predictive model included 11 predictors of rehabilitation discharge that, altogether, were used to identify 2535 subjects, among whom 808 were living in metropolitan areas, 798 in urban areas, and 929 in rural areas.

Our results generally confirm the a priori hypothesis that using the QTR straightforwardly to determine the sampling frames of trauma survivors discharged to rehabilitation from level II trauma centers would have severely underestimated their number. If we had relied solely on those data, only 275 subjects out of 8291 trauma survivors would have been identified from the eight urban or rural level II trauma centers (Table 1).

Eleven predictors of rehabilitation discharge were identified in the present study. Like Wagner et al.,19 who found rehabilitation discharge to increase 1.14 times (1/0.875 risk increase of home discharge) with each unit increase in ISS, we identified the ISS as a strong predictor of rehabilitation discharge. However, some important differences between our study and Wagner et al.’s19 have to be noted. Wagner et al.’s19 relative risk of rehabilitation discharge was identified in data that included only TBI subjects discharged to either rehabilitation settings or home. Our study involved all trauma patients with every possible discharge destination. Wagner et al.19 considered the ISS a continuous predictor, whereas we identified its most discriminant form in our data. The ISS categories that we developed for rehabilitation discharge prediction are different from those broadly used to predict mortality.31 Although much more research is needed to fully understand its role in the matter, our results indicate that the ISS might have a unique function in predicting rehabilitation discharge in general trauma populations.

Age and ALOS also were expected to predict rehabilitation discharge. Wrigley et al.,17 in a very different sample (younger; TBI only), also found that age and ALOS, both used as continuous variables, were related to referral to inpatient rehabilitation. Our analyses suggest that specific age and ALOS levels can be used to estimate the proportion of patients discharged to rehabilitation services in a general trauma population; this could be useful

| TABLE 4 Selected characteristics of the subjects included in each sampling frame |
|-----------------------------------|-----------------|-----------------|
| Age, yrs (mean ± SD)              | Metropolitan    | Urban           | Rural           |
|                                   | (n = 808)       | (n = 798)       | (n = 929)       |
| Male gender, n (%)                | 286 (35.4)      | 294 (36.8)      | 346 (37.3)      |
| Mechanism of injury, n (%)        |                 |                 |                 |
| Falls                             | 593 (73.5)      | 543 (68.0)      | 654 (70.5)*     |
| MVC                               | 185 (22.9)      | 232 (29.1)      | 249 (26.8)*     |
| Others                            | 30 (3.6)        | 23 (2.9)        | 26 (2.7)        |
| ISS (mean ± SD)                   | 13.9 ± 9.3      | 14.1 ± 9.8      | 14.3 ± 9.9      |
| Injured body regions              |                 |                 |                 |
| Head, n (%)                       | 213 (26.4)      | 191 (23.9)      | 209 (22.5)      |
| Spine, n (%)                      | 118 (14.6)      | 118 (14.8)      | 137 (14.8)      |
| Lower, n (%)                      | 650 (80.4)      | 659 (83.0)      | 797 (86.0)*     |
| Thorax, n (%)                     | 114 (14.1)      | 105 (13.2)      | 149 (15.7)      |
| ALOS, days (mean ± SD)            | 24.3 ± 18.8     | 30.5 ± 21.9     | 32.3 ± 25.6*    |
| Assisted ventilation, n (%)       | 142 (17.6)      | 132 (16.6)      | 183 (19.7)      |
| Acute-care complications, n (%)   | 360 (44.6)      | 276 (34.6)      | 601 (64.7)*     |

ISS, injury-severity score; MVC, motor vehicle crash; ALOS, acute-care length of stay.
* Variables different at the P = 0.01 level.
and practical in clinical settings. In our data, ALOS was, by far, the strongest predictor of rehabilitation discharge. This could probably be explained by the fact that ALOS in itself encompasses a number of factors potentially related to rehabilitation discharge, such as the severity of injuries and medical and/or surgical complications.

Contrary to what was expected, according to our model, trauma survivors with automobile (SAAQ) insurance coverage were less likely to be discharged to rehabilitation. This association, although statistically significant, is very close to null (odds ratio: 0.96; 95% confidence interval: 0.94 – 0.98). Given the predictive context of the analyses that did not consider confounding between variables, the automobile insurance coverage odds ratio in the model could be a statistical artifact attributable to model specification. This will have to be clarified in a further study.

The impressive magnitude of the lower-limb injuries’ odds ratio (3.0) in the model is probably linked to the important representation, in our data, of senior subjects (n = 1734, mean age = 75.9 yrs) who suffered from hip fractures as a result of falls (92.1% of hip fractures). Most of these subjects are routinely referred to in- or outpatient rehabilitation services. This also explains the sharp increase in rehabilitation discharges at the ISS of 9, which corresponds to the ISS for isolated hip fractures.

The inclusion of hip-fracture patients in the QTR results in a more elderly sample and in a larger proportion of falls as a mechanism of injury compared with some other North American trauma registries. Case criteria for entry into statewide trauma registries vary considerably. Any comparison of study results (such as ours) that emerge from North American trauma registries requires caution regarding these criteria.

Taken altogether, the 11 predictors constituted a predictive model that generated 15.9% of false-negative subjects (wrongly predicted as no rehabilitation discharge) and 40.9% of false-positives. This proportion of false-positives might seem high; however, knowing a priori that we were dealing with some remaining miscoding of the discharge destination in the dataset used to build the predictive model, we were confident that a fair proportion of those subjects would be found to be true positives (i.e., discharged to some form of rehabilitation services) once interviewed. This will have to be confirmed in the second phase of the study. For the same reason, the performance indicators reported in Tables 2 and 3 must be considered with caution.

Some differences were observed between the metropolitan, urban, and rural sampling frames of trauma survivors generated by our method (Table 4). The older age and higher frequency of falls among the metropolitan subjects may be explained by the higher number of falls in metropolitan areas and the higher mortality related to falls in subjects over 65 yrs of age in urban and rural areas. The differences in ALOS between the metropolitan and the urban/rural areas could be largely explained by some specific aspects of the healthcare system in each area. For instance, in some of the urban and rural areas, the inpatient rehabilitation services are provided in the rehabilitation unit of the same hospital. Such patients are, thus, not coded as discharged to rehabilitation in the hospital trauma registries, because they are still considered acute-care stay. Thus, in those hospitals, the ALOS was artificially longer. The higher pressure for beds in metropolitan centers might also contribute to the shorter ALOS observed in those areas. The differences observed between the three sampling frames might also be attributable, to some degree, to the fact that the predictive model developed with data from level I trauma centers might not be fully adapted for use in level II data.

One important limitation of this study is that other outcome destinations in the trauma registries, such as home with or without help and long-term care facility most likely involve some provision of rehabilitation services. However, one cannot assume that all patients coded as sent home or to a long-term care facility were indeed discharged to some form of rehabilitation service. It would have been abusive to include those destinations in our rehabilitation outcome variable. Because these two destinations are associated with less intense rehabilitation services, we can hypothesize that the predictive model developed in this study identified the most severe trauma survivors discharged to postacute rehabilitation. Thus, the complete and true population of trauma survivors discharged to a broad range of rehabilitation services remains unknown.

This work reflects some of the obstacles associated with the use of large administrative databases such as trauma registries for research purposes. The use of databases is generally faster and cheaper when the research focuses on questions that the database was designed to answer. In North American trauma-care systems such as Quebec’s, trauma registries have been used for the evaluation of prehospital and acute-care effectiveness with regard to mortality, acute complications, and resource use, most often linking them to injury severity. Consequently, much attention has been given by registry managers to controlling the quality of “early” trauma variables such as emergency and acute-care medical procedures, the coding of injuries, and mortality/survival outcome. Trauma registries have not been traditionally designed to accurately ascertain the various rehabilitation out-
comes or to be used for rehabilitation research. Besides, administrative and research use of the QTR has emerged exclusively from large metropolitan level I trauma centers. These centers have more incentive to maintain high-quality data, including outcome data. Consequently, we ran into substantial difficulties when we attempted to use the databases to identify trauma survivors discharged to various rehabilitation settings outside the large metropolitan areas. The extent of the discrepancies observed in the proportions of rehabilitation discharges in the QTR between the level I (28–39%) and level II trauma centers (0–9%) was not expected, because the latter do admit large proportions of severely injured patients (ISS ≥ 15) who are likely to require postacute rehabilitation. We did not expect the outcome data from urban and rural level II trauma centers to reflect the administrative organization of the healthcare settings in those areas rather than the “real” postacute events to such an extent. In most urban or rural areas, the in- or outpatient rehabilitation services were provided in one of the hospital wards or by rehabilitation centers administratively merged with the trauma centers. Transfers to such rehabilitation units or centers were interpreted as a continuation of the acute-care phase.

Instead of giving up on the use of the QTR to identify trauma survivors discharged to rehabilitation services, we tried to “bypass” the obstacles by using the analytical procedure presented in this paper. Even considering the difficulties we encountered, the method used to specify the sampling frames for this study was faster and cheaper. Indeed, the whole process, including authorizations from each trauma center’s research and ethics review board, data preparation, model building, and identification of the potential survey subjects, required the equivalent of one full-time research position for 6 mos. Reaching subjects across the province through different rehabilitation settings (which are much more numerous than trauma centers) would have been much more time- and resource consuming.

Obviously, the survey results will have to confirm that all the trauma survivors identified by our method were, in fact, discharged to some rehabilitation services. The differences observed among the three sampling frames generated by our method will have to be accounted for in the analyses and interpretations of the survey results that will be presented in a future paper.

CONCLUSION

The challenges encountered in this survey in trying to specify reliable sampling frames were not trivial. It was achieved with the help of statistical techniques, which, most likely, identified those among the most severe trauma survivors who could be discharged to rehabilitation services. It also led to the beginning of an understanding of the specific role of some important variables in the prediction of postacute rehabilitation discharge in a general population of trauma survivors. These results would certainly need to be replicated with data from other trauma registries.

To our knowledge, this is the first study to examine the implications of determining sampling frames of trauma survivors discharged to rehabilitation services through an acute-care trauma registry. Scrutinized examination of the data has revealed important flaws in the quality of outcome data that prevent researchers from knowing the complete size and nature of that population. If statewide trauma registries have to serve some purpose in trauma/rehabilitation research, the quality of their outcome data, other than living status, has to improve considerably to facilitate this emerging field in trauma research.

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The Reliability of Walking Tests in People with Claudication

ABSTRACT

Objective: To contrast the reliability of the 6-min walking test (6MW) with that of the shuttle walking test (SWT) in patients with intermittent claudication attributable to peripheral obstructive arterial disease (POAD), and to examine the relationships of the walking tests, medical outcomes, and hemodynamic variables.

Design: Twenty-three patients were randomly assigned to perform both walking tests on two different occasions. Total distance walked (DW), time of pain onset (PO), and time of limiting claudicating symptom (TLS) were analyzed.

Results: The reliability coefficients (ICC) generated with the 6MW for DW, PO, and TLS were 0.84, 0.81, and 0.63, respectively, and the coefficients of variation (CV) across trials were 18, 31.8, and 20.3%, respectively. With the SWT, the ICCs were 0.95, 0.72, and 0.90 for each variable, respectively, whereas the CV was 10.9% for DW, 26.8% for PO, and 9.1% for TLS. There was a significant correlation between DW and double product with the SWT (r = 0.51, P = 0.01), but there was no correlation with the 6MW.

Conclusion: Both the 6MW and the SWT are reliable walking tests for claudicant patients. However, the reliability coefficients obtained with the SWT are higher, the measurements are less variable, and there were better associations between this walking test and hemodynamic variables.

Key Words: Reliability, Walking Test, Claudication
Peripheral arterial occlusive disease (PAOD) affects 12% of the older population in the United States. In Brazil, about 11 million individuals over the age of 45 have a high probability of developing the disease. Its incidence is higher among men, and its prevalence is two times higher among African descendants and eight times more common among people with low levels of education. One typical symptom of PAOD is intermittent claudication (IC), which is defined as pain, pressure, or cramping associated with walking in one or both lower limbs, affecting either distal or proximal muscle groups. IC is caused by decreases in blood flow, leading to tissue hypoxia and, consequently, reduction of the functional activities of the patient. The claudicating symptoms usually seem to be a function of the distance and/or speed of walking and can be relieved by rest. The distance walked by patients with PAOD can be decreased as much as 50% compared with healthy individuals of the same age, because of the claudicating symptom.

The patient’s functional compromise depends both on the level of arterial obstruction and on aerobic capacity, which may be further aggravated by physical inactivity secondary to the claudicating symptom. Therefore, the more inactive the patient becomes, the more aerobic capacity deteriorates, leading to earlier muscle fatigue and a reduced willingness to walk. Hence, the walking limitation is one of the most important hallmarks related to functional impairment among patients with PAOD.

One of the ways to assess the severity of PAOD is based on the magnitude of the patient’s functional compromise while walking. The literature describes different protocols to assess function according to the time of pain-free walking or maximal walking distance, as limited by the claudicating symptoms. The use of treadmill protocols has the advantage of controlling the speed and/or inclination during the ambulation, allowing for comparisons before and after the intervention. However, the reproducibility of the time or distance of pain-free walking or maximal limiting claudication symptoms with these protocols are not yet completely satisfactory. Moreover, walking on a treadmill is not universally tolerated by patients, because it does not represent typical ambulation. In addition, the equipment is expensive and is not available in all treatment centers, particularly lower-income communities.

Alternative ways to evaluate functional limitations using walking protocols are based on endurance testing performed overground. The 6-min walking test (6MW) is a submaximal endurance test that calculates the distance after a subject has walked for 6 mins. It has been used for patients with rheumatic, neurologic, cardiac, pulmonary, and pediatric dysfunctions, and its correlation to aerobic capacity has been considered satisfactory. This test, therefore, can also be used to compare functional capacity before and after intervention, although one disadvantage is that its velocity is determined by the patients themselves, despite the supervision and encouragement from the evaluator, who, according to the previous standardization, is supposed to prompt the patient during the performance.

More recently, another overground walking test has been proposed to evaluate functional capacity among patients with different pathologies. This is the incremental shuttle walking test (SWT), which, besides imposing a similar challenge closer to the patient’s usual way of walking than that observed with the 6MW, has the advantage of having the patient’s speed controlled externally, allowing for a progressive increase of the walking effort. This is a low-cost, easily administered test, and because of its external control of speed, it has better potential for revealing the patient’s functional capacity. However, the SWT is not overly used with POAD patients, and its psychometric characteristics still need to be evaluated with this population and contrasted with different protocols concerning functional assessment. The investigation of simpler protocols that could deliver reliable results is necessary, especially in areas where economic restrictions are present.

Therefore, the objective of this study was to compare the reliability of the 6MW and the SWT and to contrast their association with measures of self-perceived levels of health that are based on the Medical Outcomes Survey (MOS-SF36) and hemodynamic variables.

**METHODS**

**Subjects**

Forty-two patients with PAOD were contacted at the Center for Treatment and Study of Peripheral Vascular Disease from the Educational Foundation of Belo Horizonte (UNI-BH) and the Clinical Hospital of the Federal University of Minas Gerais, Brazil. Patients had known diagnoses of PAOD confirmed either by a Doppler scan study and/or by the clinical presentation and classified as Fontaine stage 2 of the disease. Patient selection was independent of gender, ethnicity, or age. Patients with an asymptomatic PAOD, nonvascular claudicating pain, unstable angina, uncontrolled diabetes, resting high blood pressure, EKG suggestive of acute ischemia or uncontrolled arrhythmias, a recent episode of pulmonary embolism, or any other neuromuscular deficit precluding walking were excluded from the study. The project was approved by the local ethics committee at the UNI-BH, and all participants gave their written informed consent.
Procedures

The 6MW was conducted in a 60-m quadrangular course, with ground marks every 2 m. Each patient was oriented to walk as quickly as possible, without running or jogging, for 6 min. At each minute, a verbal command was given to the patient by the physical therapist to encourage the performance. Before beginning the testing, the patient was fitted with a Polar heart rate (HR) monitor so that the HR could be registered each minute within the test. Before and immediately after the test, blood pressure was measured. The last recorded HR and blood pressure were used for statistical analysis. The rate of perceived exertion (RPE) was assessed by the Borg scale at the end of the test. If the patient needed to stop the testing because of tiredness or claudication, he or she was allowed to rest and eventually resume the test so that the total of 6 mins was completed.

Two cones were set apart on the ground at a distance of 10 m to establish the course where the SWT was conducted. The patient started the test by walking back and forth around the cones, guided by a speed that had been determined previously by an audio signal played on a compact disc player. The initial speed was 0.50 m/sec and was increased by 0.17 m/sec each minute up to the end of the test, which could last up to 12 mins. The speed during the last stage was 2.37 m/sec. After the initial audio signal, the patient was instructed to walk to the other cone by the next sound. If the patient reached that cone before the sound, he or she was supposed to continue to walk in place until the audio signal was again heard. After completing one stage (1 min of walking), a different set of sounds was heard so that the patient would know that the speed was going to increase. At each new stage, the time between the audio signals would decrease and the patient had to increase his or her speed accordingly. The test was terminated when the patient could not reach the next cone, for two consecutive turns, by the time the audio signal was again heard. The same procedures for recording HR and blood pressure with the 6MW were repeated with the SWT.

The time of pain onset and the time of limiting pain (i.e., when the patient could no longer walk because of the high intensity of the claudicating symptom) during both tests were recorded. The total distance walked also was registered for both tests. To evaluate the reproducibility of the two tests, they were repeated a second time the next week, and the order of administration was randomly assigned. There was an interval of 20 mins between the two tests, and before the actual data collection, the patients were familiarized with the procedures.

RESULTS

Of the 42 patients contacted, 12 did not join the project because they lacked transportation, one was excluded from the analysis for not showing up for the retest, one for uncontrolled arrhythmia, two because of leg pain at rest, and three because they were not claudicants. Of the 23 patients who actually participated in the study, 9 were women and 14 were men. Table 1 provides patient demographics, medications, and associated pathologies. All patients tolerated the procedures, and there were no medical complications or emergencies during the study.

There was no difference between the mean distances covered by the patients between the two evaluations with the 6MW or with the SWT (Table 2). The ICC values indicate that both walking tests are reliable, although the SWT generated a higher coefficient. The CV values for this variable were 18% with the 6MW and 10.9% with the SWT. The mean walking distance obtained with the 6MW was statistically higher compared with the distance obtained with the SWT, in evaluation 1 \( (P = 0.017) \) and in evaluation 2 \( (P = 0.007) \).
Only eight patients during the first evaluation and nine patients during the second evaluation reached limiting claudicating pain with the 6MW, and no statistical difference was observed between the two evaluations (independent t test). The ICC2,1 of 0.63 that was evaluated with eight patients, although modest, was significant (Table 3). As for the SWT, all patients reached limiting claudicating pain, and there was no statistical difference between the two evaluations. The reproducibility of this measurement was high (ICC2,1 = 0.90) and significant (Table 3). When the time to reach limiting claudicating pain was compared between the two tests (Table 4), the patients who reached this symptom during the 6MW had an earlier onset compared with the SWT, both in evaluation 1 (\( P = 0.019 \)) and evaluation 2 (\( P = 0.016 \)). The variability of the measures with the 6MW was higher (CV = 20.3%) compared with the SWT (CV = 9.1%).

As for the time to onset of pain, only one patient during the second evaluation did not report pain with the 6MW. The mean time did not differ statistically from evaluation 1 to 2, but there was a tendency to reduce the time to onset of pain during the second evaluation. The reproducibility of this measure was high (ICC2,1 = 0.81) and significant, and the variability was 31.8%. With the SWT, three patients did not report pain on evaluation 1, one patient did not report pain in either evaluation, one reported pain during the first evaluation, and one reported pain during the second evaluation. There was no statistical difference between the mean time of pain onset between the two evaluations (independent t test), and the reproducibility assessed with 20 patients was high (ICC2,1 = 0.72) and significant. The CV for this variable with the SWT was 26.8%.

The correlations among distance walked, time of pain onset, and time of limiting pain were also analyzed for consistency of results within each test. For the 6MW, the Pearson correlation between distance walked and time of pain onset was 0.41 (\( P = 0.057 \)), whereas the Spearman correlation between distance walked with time for limiting symptom was 0.21 (\( P = 0.60 \)). There was a strong, significant Spearman correlation between time for pain onset and time of limiting symptom (\( r = 0.92, P = 0.01 \)). With the SWT, Pearson correlations were 0.75 (\( P = 0.0001 \)) for distance walked and

<table>
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<th>TABLE 1 Patient characteristics (n = 23)</th>
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<tr>
<td>Age, yrs</td>
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<td>Height, cm</td>
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<td>Body weight, kg</td>
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<tr>
<th>Associate Conditions</th>
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<tr>
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<td>Diabetes</td>
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<td>Diuretic</td>
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<td>Stable angina</td>
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<td>ACE inhibitor</td>
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<td>Cardiac arrhythmia</td>
<td>2</td>
<td>Calcium-channel blocker</td>
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<td>Congestive heart failure</td>
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<td>AT-1 receptor blocker</td>
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<td>Thromboangitis obliterans</td>
<td>1</td>
<td>Central alpha-adrenergic agonist</td>
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<td>Dyslipidemia</td>
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<td>Vasodilator</td>
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<tr>
<td>6MW</td>
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<td>SWT</td>
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6MW, 6-min walking test; SWT, shuttle walking test; ICC2,1, intraclass correlation coefficient model 2,1. \(^a\) Significance level between evaluation 1 and evaluation 2; \(^b\) significance level of the ICC. n, number of participants.
time of pain onset, 0.77 (P = 0.0001) for time of pain onset and time of limiting symptom, and 0.93 (P = 0.0001) for distance walked and time for limiting symptom.

There was no difference between the mean values of HR, systolic blood pressure (SBP) or diastolic blood pressure (DBP), or RPE between evaluations 1 and 2 in either the 6MW or the SWT, although there was a tendency for these values to be higher with the SWT. The SWT generated higher mean values of HR and DBP than the 6MW during the second evaluation (Table 5). The ICC2,1 for HR was 0.61 (P < 0.0001) for the 6MW and was 0.81 (P < 0.0001) for the SWT. As for the SBP, this coefficient was 0.75 (P < 0.0001) and 0.39 (P = 0.03) for the 6MW and SWT, respectively.

There was no correlation between the rate–pressure product (HR × SBP) with distance walked and time of limiting claudicating pain during the 6MW, whereas with the SWT, these correlations were r = 0.51 (P = 0.01) and r = 0.44 (P = 0.03), respectively. The rate of perceived exertion did not correlate with any of the hemodynamic variables or with the performance during the walking tests.

Twenty-two patients completed the SF-36. One patient’s data were incomplete and were excluded from analysis. The mean score for physical functioning was 44.31 ± 17.55; for physical role, 44.32 ± 38.52; for bodily pain, 55.23 ± 20.99; for general health, 58.95 ± 16.31; for vitality, 55.23 ± 17.96; for social functioning, 72.3 ± 25.80; for emotional role, 45.42 ± 46.63; and for mental health, 59.23 ± 15.72. The items related to physical functioning and for physical and emotional limitations had the lowest scores. Table 6 relates the correlations between the physical and mental health components with the performance on the two walking tests. The 6MW had high, significant correlations only when the time of pain onset and the physical and mental components of the SF-36 were analyzed. Correlations among the two components of the SF-36 and the performance during the SWT were present (ranging from 0.33–0.48) with distance walked, time of pain onset, and time for limiting claudicating pain. These correlations were statistically significant only with the mental health component. The correlation between time of pain onset and the physical health component during the SWT was low and not significant.

**DISCUSSION**

The objective of this study was to contrast the reliability of the 6MW and SWT in registering the time of pain onset and time of limiting claudicating symptom while walking, as well as the total distance covered by the patients with PAOD. Both tests generated high reliability coefficients for distance walked, although the SWT demonstrated a higher coefficient and less variability than did the 6MW. The findings observed with the 6MW are corroborated by the literature, not only in relation to the distance walked but also in relation to the other variables analyzed. In other studies, for example, the distance walked varied from 382 ± 12 to 433 ± 11 m with patients with PAOD, although the test–retest reliability was high with small variability (r = 0.94 and CV = 10.4%). This tendency can be observed when the 6MW is used with patients with congestive heart failure (ICC >0.95, CV >1.9%), although the distances walked are more variable. When the variability of distance walked during both tests of this study was co-
trasted, a CV of 18%, as observed with the 6MW, would mean that if a patient in one evaluation reached a distance of 300 m, his or her distance walked in a subsequent test could vary by 54 m. With the SWT, a CV of 10.9% would mean that the variability in another test would be 32.7 m.

The comparison between the data obtained with SWT and the literature was less fruitful, because this test has not been used universally with PAOD patient populations. Manfredini et al.21 have proposed a diverse protocol to evaluate claudicating patients’ performance with an incremental shuttle walking test to verify the reliability of speed of pain onset, rather than time, but they do not indicate the distance walked. Zwierska et al.22 have reported a lower mean distance walked (217 ± 17 m) after three assessments with SWT as compared with the present study, with high reliability indexes (ICC = 0.88; CV close to 16%). These reliability indexes were smaller than the ones found in our study. Walker et al.11 report a median maximal walking distance of 170 m (ranging from 120 to 301 m) and report a CV of less than 10% according to previous research using the SWT. There are data on the SWT that are based on different groups of patients. In a study conducted with heart-transplant patients, the mean distance walked with the SWT was close to 400 m, and the reliability test–retest of this variable was 0.90.23 In patients with heart failure, the average distance walked between two tests was approximately 515 m, the test–retest reproducibility coefficient was 0.98, and the CV was 6.9%.24 Distances covered with patients with limiting airflow disease varied from approximately 272 m25 to 391 m,26 and the reliability of the SWT in this population is also high.9 As for patients with claudication secondary to spinal stenosis, the mean walking distance with the SWT was 150 m, and test–retest reliability was high (ICC = 0.90).27 Thus, the SWT is reliable in assessing the distance walked, not only with claudicating patients secondary to PAOD but with different pathologies as well.

Fewer than half of the patients analyzed in this study (39%) had to interrupt the walk because of the limiting claudicating symptom during the 6MW. Despite this test being conducted with the therapist encouraging the patient during the performance to walk as quickly as possible, few patients reported the limiting symptom; with them, the correlation between the distance walked and the time of the limiting claudicating symptom was weak and nonsignificant (r = 0.21, P = 0.60). This suggests either that the patients had more control during the performance of the test and did not walk quickly enough, or that the time of the testing (6 mins) was not sufficiently long to allow for the limiting symptom to manifest. The data also suggest that the patients might have walked at lower speeds during the 6MW, because the distances walked with the two tests were not significantly different.

| TABLE 5 Hemodynamic variables and rates of perceived exertion (RPE) |
|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|                          | 6MW                      | SWT                      | 6MW                      | SWT                      |
|                          | Evaluation 1             | Evaluation 2             | P*                        | P***                     |
| HR, bpm                  | 108.83 ± 13.74           | 109.13 ± 15.53           | 112.48 ± 18.84            | 114.7 ± 16.47            | 0.22                     | 0.039                   |
| SBP, mm Hg               | 157.17 ± 21.68           | 156.52 ± 21.45           | 160.87 ± 23.72            | 161.09 ± 25.94           | 0.40*                    | 0.44*                   |
| DBP, mm Hg               | 83.48 ± 11.52            | 79.13 ± 14.11            | 85.22 ± 10.82             | 83.04 ± 12.95            | 0.52                     | 0.05                    |
| RPE                      | 12.83 ± 2.76             | 11.87 ± 2.94             | 12.57 ± 2.76              | 11.91 ± 2.97             | 0.60*                    | 0.88*                   |

6MW; 6-min walking test; SWT, shuttle walking test; SBP, systolic blood pressure; DBP, diastolic blood pressure. * Significance level between 6MW and SWT at evaluation 1; ** significance level between 6MW and SWT at evaluation 2. * Wilcoxon.
walked up to the limiting symptom were statistically higher than those with the SWT in both evaluations. The fact that the Spearman correlation was high and significant between the time of pain onset and the time of limiting symptom during the 6MW indicates that during this protocol, the times to reporting the two symptoms are strongly related. As for the SWT, there was a higher consistency among those variables because all Pearson correlations were strong and statistically significant.

With the SWT, 100% of the patients had to interrupt the test because of the limiting claudicating symptom. Moreover, there was an excellent association (\( r = 0.93\% \), \( P < 0.0001 \)) between the time of limiting claudicating symptom and the distance walked during the SWT. This higher correlation observed with the SWT indicates that this test may be more consistent when evaluating the claudicating patients. These data, when analyzed in conjunction with the hemodynamic variables, suggest that the SWT imposed a more uniform load on the patient than did the 6MW. It means that the patients had better external control of their performance while performing with the SWT protocol.

This study also confirms that the time to pain onset is more prone to variability than is the total distance walked, as observed in different protocols. In a study with claudicating patients during the 6MW, about 69% of 64 patients reported pain onset in a mean time of 135 \( \pm \) 59 secs. The test–retest correlation of this variable was an ICC of 0.75 and a CV of 47%,\(^8\) Other studies on reliability generated a high coefficient (0.95) for time of pain onset during the 6MW\(^4\); when the test was conducted with the constant treadmill protocol, the coefficient was 0.55, and when the protocol was progressive, the coefficient was 0.89.\(^28\) In one study conducted with 10 claudicating patients secondary to PAOD using a diverse incremental shuttle-walking test protocol, the test–retest reproducibility of pain onset reported on speed was 0.98.\(^29\) Walker et al.\(^11\) also report that the reliability of time and distance of pain onset were high with the SWT, with a CV less than 10%. In the present study, the reliability coefficient for time of pain onset during the 6MW (ICC\(_{2,1} = 0.81\)) was slightly higher than the coefficient observed during the SWT (ICC\(_{2,1} = 0.72\)); however, the CV obtained with the SWT had 5% less variability (26.8% vs. 31.8%) in this variable compared with the 6MW.

These walking tests are used more often to evaluate walking performance before and after intervention. However, because the main rehabilitative procedure suggested for patients with PAOD is based on walking, the association between symptoms and time, distance, or speed obtained from these tests can be potentially useful in prescribing specific intensities for this activity. With the 6MW, it is possible to get an average time of pain onset, but not exactly a precise speed (i.e., walking intensity), because the patient has more control of his or her gait velocity during the performance. In contrast, with the SWT, it is possible to determine the intensity of walking, because the onset of pain, which occurs in a given stage of the test, corresponds to a specific walking speed. Therefore, individualized walking speeds below, at, or higher than the onset of pain, or at a percentage of the limiting claudicating speed, can be prescribed during rehabilitation.

It has been suggested that the SWT generates a higher cardiovascular load because it is progressive and symptom limiting compared with other walking tests with submaximal features, such as the 6MW.\(^{23,24}\) Yet, the data gathered in the present study do not confirm this assumption. The mean HR and DBP were higher with the SWT only during the second evaluation, but there was no difference with the SBP and RPE between the two trials. Nonetheless, there was a tendency for HR, SBP, and DBP to be higher with the SWT in both evaluations when compared with the 6MW. The moderate but significant correlation between the double product with distance walked and with time of limiting claudicating symptom during the SWT suggest that performance with this test is more consistent—that is, the physical performance has stronger correlations with the cardiovascular parameters—but this does not imply that it is more strenuous for the patients when compared with the 6MW.

Vagaggini et al.\(^{25}\) however, compared the 6MW with the SWT in patients with chronic obstructive pulmonary disease and did not report that the latter imposed a higher cardiorespiratory overload for these patients. There was no substantial difference between the distances reached, or between the cardiorespiratory variables analyzed, in either test.\(^{25}\) There was a strong, significant correlation between the distances walked in both tests (Spearman coefficient = 0.85, \( P < 0.0005 \))—a correlation superior to the one obtained in the present study (Pearson correlation = 0.54, \( P = 0.007 \)). In another study on chronic obstructive pulmonary disease patients, even though the distances obtained with the 6MW and the SWT were similar, only the latter generated strong, significant correlations with cardiorespiratory parameters.\(^{26}\) In that study, the authors conclude that the SWT is more accurate than the 6MW for evaluating the performance of patients with chronic obstructive pulmonary disease.\(^{26}\) With heart failure patients, the peak HR and RPE were higher with the 6MW than with the SWT, although there was a tendency for a
higher oxygen consumption with SWT compared with the 6MW.\textsuperscript{24}

The literature suggests that the SF-36, particularly in the physical function domain, is capable of detecting changes after an intervention program with POAD patients.\textsuperscript{11,29} There are other studies in which the SF-36 scores did not change,\textsuperscript{15} or in which the improvement varied from 38 to 67% with the domains related to physical health.\textsuperscript{14} With patients who had sequelae from poliomyelitis, the distance walked during the 6MW correlated moderately ($r = 0.67$) with the physical domain of the SF-36\textsuperscript{30}; for heart failure patients, this correlation with physical function was $r = 0.62$.\textsuperscript{31} Bauman and Arthur\textsuperscript{32} report that the correlation between physical health and the distance walked during the 6MW was 0.57, and the SF-36 scores were lower on the physical function domain. Therefore, the SF-36, even though not specific for patients with PAOD, adds information on the general health status of the claudicating patient, particularly in the physical health domain. In the present study, the subscales based on physical functioning (44.31 ± 17.55) and role physical (44.32 ± 38.56) generated lower scores, except for the subscale emotional. With the 6MW, the correlations between physical and mental health were either weak and/or nonsignificant or negative, except for the correlation with time of pain onset. With the SWT, the magnitude of the correlations of the mental and physical health components were all positive and generated scores between 0.33 and 0.48, except for time of pain onset, which was 0.17. Therefore, when the patterns of the correlation between the different domains of the SF-36 and the SWT are analyzed, they are more favorable to the validity of this walking test in evaluating a patient’s general perception of health-related aspects than is the 6MW for people with POAD.

**CONCLUSION**

This study indicates that both walking tests are reliable and useful for clinical purposes with patients who claudicate because of PAOD. The SWD, however, may be preferable with this population because it has generated higher indexes of test–retest reliability and lower variability. It also has demonstrated more consistency among the test outcomes (distance and symptoms), stronger correlations with hemodynamic variables, and more uniform association with measures of subjective perception of health-related quality of life (SF-36).

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Space Flight Rehabilitation

ABSTRACT


The weightless environment of space imposes specific physiologic adaptations on healthy astronauts. On return to Earth, these adaptations manifest as physical impairments that necessitate a period of rehabilitation. Physiologic changes result from unloading in microgravity and highly correlate with those seen in relatively immobile terrestrial patient populations such as spinal cord, geriatric, or deconditioned bed-rest patients. Major postflight impairments requiring rehabilitation intervention include orthostatic intolerance, bone demineralization, muscular atrophy, and neurovestibular symptoms. Space agencies are preparing for extended-duration missions, including colonization of the moon and interplanetary exploration of Mars. These longer-duration flights will result in more severe and more prolonged disability, potentially beyond the point of safe return to Earth. This paper will review and discuss existing space rehabilitation plans for major post-flight impairments. Evidence-based rehabilitation interventions are imperative not only to facilitate return to Earth but also to extend the safe duration of exposure to a physiologically hostile microgravity environment.

Key Words: Space Flight, Rehabilitation, Weightlessness, Disability

The weightless environment of space forces physiologic adaptation on all systems of the human body. A period of disability follows space flight and may last from days to weeks as the body readapts to full gravity. Physiologic adaptation to microgravity is dependent on exposure, with greater levels of disability anticipated on returning home from longer missions. Astronauts' physiologic adaptations to the extreme environment of space cause impairments and disabilities that may not be fully reversed on return to Earth. To date, space medicine has focused primarily on preflight preparation and potential acute problems of space flight; however, knowledge and understanding of the consequences of weightlessness, combined with the expertise of medical rehabilitation specialists, can converge to extend the hard ceiling of space-mission duration.

Disability after a space flight is dependent on three major factors: amount of time spent in space, individual adaptation to weightlessness, and efficacy of countermeasures. Because space agencies are currently preparing for longer-duration missions than ever before, greater levels of postflight disability are inevitable. We are currently unable to predict individual adaptation to weightlessness, and therefore we cannot preselect astronauts who adapt with relative
Patient populations, such as those with limited mobility or confinement to bed, are often treated by physiatrists. These patients may develop physiologic changes that resemble those experienced by astronauts during space flight. Therefore, physiatrists are well-suited to develop optimal rehabilitation strategies for returning astronauts.

Short-duration flights are defined as less than 30 days, encompassing typical shuttle missions of 10–17 days. Most data on space physiology have been derived from these short-term stays in space. Long-duration missions, including a 6-month-average stay on the International Space Station, are distinct from short-duration flights in regards to their increased emphasis on countermeasures. Eventually, there may need to be a category for ultra-long-duration space travel corresponding to the time required for extended lunar colonization or interplanetary travel to Mars (approximately 3 yrs) or beyond. To date, the longest uninterrupted exposure to space has been 437 days (Cosmonaut Valery Polyakov). The longest cumulative time in space was 747 days throughout a total of three flights (Cosmonaut Sergei Avdeyev). Rehabilitating astronauts to return to 1 g (Earth gravity) after years of space travel will prove to be the most challenging.

Data on space adaptation and rehabilitation are sparse and have been derived mainly from limited studies on astronauts and from Earth-based models of weightlessness. The ideal study is frequently compromised by payload restrictions and limited time available for the crew members who need to act as in-flight scientists on top of other high-priority tasks. Additionally, a potentially large amount of rehabilitation data may not have been systematically collected for publication. As a result, existing space-flight studies lack the statistical power (low subject numbers), control groups, and blinded interventions that provide the essential tenants of evidence-based practice. Nevertheless, existing studies provide the foundation for future research.

The bed-rest model, used to mimic human weightlessness, constitutes a direct link with rehabilitation medicine. In bed-rest studies, subjects follow a strict protocol of lying down in bed at a 6-degree head-down tilt for days to months. Physicians provide care to people whose conditions limit their mobility or confine them to bed. Some of these populations, such as spinal cord injury patients, severely deconditioned or nutritionally deficient patients, and the elderly, undergo physiologic changes that highly correlate with those seen in astronauts. Physicians routinely deal with problems similar to both space and bed-rest models, including cardiovascular deconditioning, fluid shifts, muscular atrophy and deconditioning, nutritional problems, bone demineralization, anemia, immunosuppression, endocrine alterations, and neurosensory vestibular dysfunction. As such, physiatrists are ideally suited to develop optimal rehabilitation strategies for returning astronauts.

Furthermore, rehabilitation patients will profit from space research. The early emphasis of space development was with regards to physics, engineering, and hardware, not biological sciences. Thus far, spinoffs directly benefiting rehabilitation patients have mainly been technology transfers.

Recently, NASA identified the human as an essential element within the systems of space flight, calling for increased attention to the biology and physiology of human space flight.

This paper will review space-related physiologic adaptations in three sections: (1) cardiovascular, (2) musculoskeletal, subdivided into muscle and bone, and (3) neurovestibular. Other affected systems (i.e., gastrointestinal, hematologic, renal, etc.) are less amenable to rehabilitation and will not be reviewed here.

**CARDIOVASCULAR**

Cardiovascular deconditioning seen with space flight includes decreases in circulating blood volume, diastolic blood pressure, left ventricular mass, and ventricular stroke volume. These alterations are dose dependent on exposure to microgravity and may lead to dizziness, tachycardia, palpitations, or reduced exercise capacity. Arrhythmias do not routinely occur during or after flight. The most immediate and troublesome manifestation for the astronaut on return to Earth is post–space-flight orthostatic intolerance (PSOI).

PSOI is caused by insufficient perfusion of the brain and presents as syncope or presyncope (light-headedness, dizziness, graying out, or systolic blood pressure below 70 mm Hg). First fully documented after the 34-hr Mercury flight in 1963, PSOI occurs in 20–64% of returning astronauts. Some astronauts are predisposed to this postflight complication and do not develop resistance to PSOI with subsequent flights. Women are particularly susceptible to PSOI. Long-duration space flight greatly increases the incidence of PSOI compared with that of short missions.

The mechanism of PSOI is likely multifactorial, although it is not yet completely understood. Extensive reviews of this topic have been published. Early hypotheses for contributing factors were mechanical in nature and included (a) fluid loss and blood-volume contraction, (b) muscular wasting, (c) impaired cardiorespiratory performance, and (d) increased venous compliance.

More recent hypotheses include (e) vestibular oto-lith organ morphological and neurological plasticity with altered cardiovascular control, (f) post-
flight hypoadrenergic responses or impairment of the adrenergic loop, and (g) impaired baroreceptor reflex arcs. Furthermore, space-flight anemia with short-duration and long-duration flights may contribute to insufficient brain oxygenation.

Countermeasures with oral saline fluid loading immediately before landing initiates the readaptation procedures. Lower-body negative-pressure devices create a vacuum around the lower body and temporarily simulate dependent blood distribution seen in normal gravity. Despite encouraging early experimental data, lower-body negative-pressure devices have not yet demonstrated fully protective effects against PSOI to justify their routine use in space. During reentry, astronauts wear advanced crew escape suits that contain antigraft suits and liquid cooling garments. The antigraft suit consists of inflatable bladders on the legs and abdomen, and the liquid cooling garment circulates thermodis-electrically cooled water through a network of tubes covering the body. These suits offer transient cardiovascular protection by supporting the blood pressure and limiting increases in heart rate. Within minutes of return to 1 g, medical rehabilitation management may include further fluid resuscitation and, rarely, the use of inotropic agents. Fludrocortisone, a mineralocorticoid, has been shown to improve plasma volume, but it does not reduce the symptoms of PSOI, suggesting that reduced fluid volume alone is not responsible for PSOI. Midodrine, an alpha-1 agonist, may limit PSOI.

Readaptation to increased gravity is the most physiologically demanding phase of space flight, in part because of the immediate consequences of PSOI. Although syncope is accommodated on return to Earth by a medical ground crew, astronauts will not be afforded such ground support in either a planned or an emergency egress on the moon (0.16 g) or Mars (0.36 g). Hindered human performance on landing can put lives and the mission at risk, because life-support systems must be configured immediately during this critical period. Recovery from PSOI, with the disappearance of hypotension and presyncope, is usually complete by 3 days to 2 wks after landing. Recovery of heart rate, blood pressure, stroke volume, left ventricular mass, and cardiorespiratory responses is expected to occur during rehabilitation.

**MUSCULOSKELETAL: BONE**

Perhaps the best known effect of space flight is the loss of bone mass, which is accelerated by a factor of 10 compared with Earth. Bone mineral density (BMD) in weight-bearing bones typically decreases by approximately 1.0% per month, although it may decrease in some sites by up to 2.0% per month. At this rate, BMD could theoretically decrease by half during a mission to Mars and may be incompatible with safe return to 1 g. The decrease in BMD is thought to result from decreased mechanical loading in microgravity and is often likened to an accelerated age-related osteoporosis seen on Earth.

Decreases in BMD vary between individuals and are site dependent. The greatest amount of bone loss is in larger, locomotion and Earthbound weight-bearing bones of the lower extremity, including the distal tibia, femoral neck, pelvis, and lumbar vertebrae. BMD remains essentially unchanged in non-weight-bearing bones of the upper limbs and actually increases in the skull. Trabecular bone density decreases earlier and by a greater percentage than cortical bone, although more absolute mineral mass is lost from cortical bone. At the cellular level, decreased mechanical forces on bone may directly or indirectly act to stop the differentiation of mesenchymal stem cells into osteoblasts.

Bone mineral depletion seems only partially reversible on return to Earth because BMD failed to recover to preflight values after 6 mo and in limited 5-yr follow-up data. Progressive degradation of the skeletal system, unless arrested by countermeasures, may be a factor limiting space travel. It is unknown whether bone loss is slowed or whether it eventually plateaus with long-duration flights. Complicated osteoporosis, including fractures of the hip, radius, or spine, have not been documented in spaceflight literature, but these conditions will need monitoring with longer flights. BMD provides only a surrogate measure for true fracture risk.

Bone rehabilitation aims at preventing bone loss and promoting osteogenesis by mechanical loading while avoiding fractures in osteopenic bone. The greatest osteogenic effects come from repeated short-duration high-strain activities directed to a specific bone site. In-flight countermeasures for bone loss have typically included exercise on treadmills, cycle ergometers, and resistance exercise devices. Russian cosmonauts also use Penguin loading suits to produce 70% of axial static and dynamic body weight during treadmill training. Unfortunately, the ideal countermeasures are as yet unknown; investigation is underway to augment existing countermeasures with short-term, high-impact mechanical stimuli, with extremely low-magnitude, high-frequency mechanical stimuli, or with regularly scheduled centrifugation.

The role of bisphosphonate medications in space-flight osteoporosis is as yet unclear. These medications inhibit osteoclastic resorption of bone, but the relative contribution of increased bone resorption vs. decreased bone formation in space has not yet been delineated. The use of bone-
musculocutaneous agents such as parathyroid hormone, fluoride, or insulin-like growth factor has not been established in this population, although this is a logical research option to investigate. Calcium and vitamin D are essential for bone integrity and must be represented in the diet, both during flight and rehabilitation phases. Recent evidence supports the role of vitamin K in inhibiting osteoclastic bone resorption in space flight, and vitamin K should be incorporated in the diet.38

Postfracture rehabilitation of osteoporotic patients is aimed at mobilization and pain control by using a supervised, progressive, resistive exercise program. Vibration platforms seem promising for terrestrial and space-flight osteoporosis but are still under early investigation.46,49

MUSCULOSKELETAL: MUSCLE

Performance of activities of daily living in space, as on Earth, depends on sufficient functional muscle mass. However, the force needed to perform these activities is reduced in space. Progressive muscular atrophy in weightlessness has been consistently documented.20,50–55 In the absence of countermeasures, muscle mass plateaus at about two thirds of initial mass after approximately 270 days.20 Muscular integrity is needed for emergency maneuvers, high-performance duties such as extravehicular activities (e.g., space walks), using tools, mobility, and, possibly, to limit the degree of PSOI upon return to Earth. The loss of muscle mass, force, and power, abnormal reflex patterns, and increased fatigability from space flight corresponds in many aspects to the deconditioning suffered by bed-rest patients and elderly patients on Earth.4,56

Actual and simulated weightlessness have demonstrated that atrophy is greatest in postural antigavity muscles.20,55,57 Loss in muscular volume is greatest in ankle plantarflexors, followed by dorsiflexors, knee extensors, knee flexors, and lower-back muscles.56 Short-duration space flight results in a decrease in fiber cross-sectional area but no change in fiber number. Unlike animal models, where type I fibers preferentially atrophy, humans in microgravity display atrophy of both type I and type II fibers.59,60 Atrophy is determined more by muscle function than fiber composition, because atrophy of both types is largest in predominantly slow-twitch, postural muscles and milder in predominantly fast-twitch, nonpostural muscles.61 This atrophy has been attributed to an imbalance between increased myofilament protein degradation and decreased synthesis when exposed to microgravity.54

However, more clinically important than structural changes in muscle mass, decreases in force and power have been measured in space.60 Despite the use of countermeasures, maximal strength was reduced to 45% of preflight values after 180 days on Mir.62 Additionally, postflight muscles have lost explosive power, greatly exceeding the moderate loss of muscle bulk. Functional muscle losses may be attributable to changes in neural activation.59 Conduction velocity in axon terminals is decreased with space flight,63 and neuromuscular junctions undergo significant structural remodeling in postural muscles exposed to microgravity.61

The discord between mass, force, and power may also be attributable to altered biomechanical properties of muscles in microgravity. Higher44 and lower,65,66 musculotendinous stiffness has been reported after space flight, depending on the measurement techniques employed. Flywheel exercise resistance blunts the decrease but does not prevent alterations in tendon stiffness during bed rest.66 Impaired control of length–tension relationships during contraction may contribute to functional weakness and predispose to injury.

The efficacy of countermeasures for muscular atrophy (aerobic exercises on cycle ergometers and treadmills, resistance exercises, and leucin-rich diet) is not known because protocols have not been standardized and studied. Extrapolating from bedrest data, the ideal muscular countermeasures would include isometric and isotonic high-intensity impact exercises.50 Eccentric contraction training with the flywheel resistance device has preserved knee-extensor mass, blunted planterflexion muscle loss, hypertrophied chronically unloaded muscle, and attenuated bone loss in bed-rest studies.57,69 Regular, rapid muscle contractions during flight may prevent explosive force deficits seen on return to Earth.

Because countermeasures cannot yet preserve muscles, astronauts require neuromuscular readaptation to gravity and currently receive physical therapy similar to a regimen for generalized deconditioning. Restoration of muscle mass and strength occurs at a rate similar to, or possibly shorter than, the rate of initial atrophy.57,58 We could not find any studies comparing the efficacy of various rehabilitation protocols applied to astronauts after extended missions.

One last peculiar concern is the persistent postflight muscle soreness reported by astronauts up to months following return to Earth.60 The exact cause of this soreness is unknown, but it could be related to damage in fibers preferentially atrophied during weightlessness and, subsequently, challenged with eccentric loading.50,53 Rat muscle biopsies that were normal in flight demonstrated extensive sarcocmere disruption and edema within hours of returning to 1 g.70 The closest clinical corollary to this condition may be delayed-onset muscle soreness after
excessive athletic activities, or that reported by rehabilitation patients after a period of non-weight bearing.\textsuperscript{71} Nonsteroidal antiinflammatory medications and massage may provide symptomatic relief.\textsuperscript{72} Muscle soreness may limit both the intensity of rehabilitation exercises and the use of aggressive eccentric activities.

**NEUROVESTIBULAR**

Astronauts experience a number of vestibular and sensory symptoms during and after flight, including postural ataxia, peripheral proprioceptive deficits, gaze instability, oscillopsia, impaired spatial orientation, visual vection illusions, and functional motor planning problems.\textsuperscript{73} Comprehensive testing can detect complex vestibular symptoms in all astronauts within a few hours of landing. Space motion sickness, which has been likened to but is different from terrestrial motion sickness, is caused by exposure to provocative real or apparent motion and is estimated to affect 80–90% of all crew members when changing gravitational fields.\textsuperscript{73} Neurovestibular disturbances have been attributed to impaired integration of central and peripheral signals from various sensory systems. Changing visual reference frames, otolith organ unloading, and peripheral proprioceptive deficits in microgravity are believed to play key roles.\textsuperscript{74,75}

Neurovestibular disturbances are common in astronauts after space flight as sensory systems readapt to gravity. The most common symptoms are clumsiness (reported by 69% of astronauts), difficulty walking in a straight line (66%), persisting sensation aftereffects (60%), vertigo while walking (32%), vertigo while standing (29%), nausea (15%), difficulty concentrating (10%), and vomiting (8%).\textsuperscript{76}

Although symptoms are generally described as mild or moderate in intensity, they may be sufficient to affect astronaut well-being or mission safety. In space, impaired neuromotor performance would endanger the crew during emergency egress from an orbiter or could delay planned construction goals with planetary missions. These symptoms have not been lessened by any current countermeasures.\textsuperscript{76}

Symptoms are typically self-limited to a few weeks in duration but can recur intermittently and unpredictably during this time. These paroxysmal disturbances increase the risk for falls during rehabilitation or in routine tasks such as driving, running, or maneuvering stairs. Motor actions that are fully automated before flight may require greater cognitive awareness and visual inputs to achieve a similar motor outcome during readaptation.\textsuperscript{77} Rehabilitation exercise prescription needs to accommodate these unpredictable limitations.

Research is underway to guide neurovestibular rehabilitation.\textsuperscript{78} Preflight training and onboard countermeasures of dual adapted states are being tested.\textsuperscript{78,79} No preventative medications are known. Similar to PSOI, potentially high-risk situations can be averted when returning to Earth, but prevention might not be possible on lunar or Martian soils in the absence of ground rescue personnel.

**RADIATION RISKS AND REHABILITATION**

Space-flight radiation poses severe and currently irreversible threats to astronauts and may result in sizable risks in interplanetary missions. Long-duration exposure may contribute to cataracts, immune system dysfunction, sterility, damage to the central nervous system, genetic mutation, and cancers.\textsuperscript{80–85} Lingering effects of radiation on an astronaut during the rehabilitation phase is unknown to date. Strategies for risk mitigation revolve around shielding, because no rehabilitation interventions can reverse radiation exposure.\textsuperscript{86}

**CURRENT POSTFLIGHT REHABILITATION STRATEGIES**

In 1997, NASA developed a postflight rehabilitation plan for crew members returning from long-duration missions.\textsuperscript{87} This document was based on short-duration flights and before habitation of the International Space Station. The plan outlines personnel, equipment, facilities, and schedules for rehabilitation. Medical support is overseen by the crew surgeon and may involve consultation with physical medicine and rehabilitation specialists as needed. Currently, international crews returning from the International Space Station initiate rehabilitation efforts at the landing site regardless of location. North American astronauts continue their rehabilitation as soon as possible in Houston, Texas, and Russian cosmonauts return to Star City, Russia; we will review the former in detail. Astronauts have 2 hrs/day of protected rehabilitation time for the first 45 days, during which time rehabilitation interruptions (for appearances, interviews, etc.) must be approved by medical operations. The rehabilitation plan is divided into four phases.

Phase 0, the landing/egress phase, incorporates activities from shuttle-hatch opening until arrival in Houston. This usually occurs entirely on landing day (return + 0 days) but may include the next day (return + 1 day), depending on the landing site. Immediate measures are aimed at symptomatic treatment of orthostatic intolerance and vestibular dysfunction.

Phase 1 follows until return + 3 days and addresses the acute effects of readaptation. Priorities of this phase include rest, family time, psychological support, physical assessment, circadian rhythms activities from shuttle-hatch opening until arrival in Houston. This usually occurs entirely on landing day (return + 0 days) but may include the next day (return + 1 day), depending on the landing site. Immediate measures are aimed at symptomatic treatment of orthostatic intolerance and vestibular dysfunction.

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rhythm adjustment, and injury prevention. Physical activities begin with stretching exercises, massage, and assisted walking as tolerated.

Phase 2 lasts from return + 4 days until return + 14 days and focuses on incremental physical conditioning. Stretching and massage continue, and progressive strengthening is introduced using resistance devices. Astronauts receive cardiovascular fitness training with the use of standard treadmills and cycle ergometers. Hydrotherapy is advocated early and, based on the water depth, provides graded levels of lower-extremity loading. Fatigue is a common problem during this phase and may require frequent rest periods. Astronauts returning from short-duration flights often feel that they have returned to baseline on completion of this phase.

Phase 3 completes the rehabilitation activities by day of return + 45 days. The goal of this final phase is to obtain preflight levels of fitness in preparation for return-to-flight status. Medical supervision continues but is less intense. Aerobic and anaerobic activities continue, with increased focus on proprioceptive and agility training. Use of a vibration platform has recently been initiated to stimulate bone formation, although its efficacy in the astronaut population needs to be established. The crew surgeon may extend the rehabilitation program as indicated.

Each phase of this rehabilitation plan, at each phase, is based on short-term mission experience. In practical application, it is highly customized to the crew’s medical status and training preferences. Anecdotally, astronauts and therapists believe these exercises and duration of rehabilitation are sufficient for full return to preflight physical status. Only recently have standardized outcome measures been collected on strength, agility, and overall fitness before and after long-duration flights. Thus far, the number of astronauts returning from Mir or International Space Station astronauts has been too small to draw solid conclusions. These raw data will eventually be used to build an evidence-based postflight rehabilitation program.

**ADAPTING TO CHANGING GRAVITATIONAL ENVIRONMENTS**

Physiologic space-flight data suggest that it is more difficult to return to gravity than to adapt to microgravity. This is remarkable because it means that after millennia on Earth, human beings can adapt quickly to an exceptionally different environment. Yet, after just weeks away, humans require prolonged and extensive rehabilitation in readapting back home. The most demanding physical requirements of space travel occur when transitioning between gravitational fields. This has obvious implications, not only when returning to Earth, but also for establishing colonies on Mars, where partial gravity exists after weightless space travel. Research in rehabilitation after space flight should seek to delineate the apparent asymmetric plasticity of the human nervous system and homeostatic adaptability to maximize functional performance of astronauts during transitions between such gravitational forces.

Although the investment into countermeasures both in time and equipment may not be rewarding for short-duration flights, countermeasures seem indispensable in long-duration flights. Individual exercise-countermeasure compliance may correlate with the variability seen in postflight disability, but this needs to be verified in future missions.

Inevitably, unexpected medical events such as injury, fracture, or severe medical illness (i.e., requiring operative intervention) will occur in space. In low Earth orbit, astronauts may return to Earth for medical management and rehabilitation. This rehabilitation must proficiently address both the acute problem as well as the complications of postflight readaptation.

If returning to Earth is timely or possible, as during interplanetary exploration, in-flight rehabilitation after acute injury may be needed before return to active flight duty. Arguably, this in-flight rehabilitation will be even more pressing than its terrestrial counterpart because of the reliance of the mission on each crew member. Although redundancy among crew members is built into all essential operations, every astronaut contributes special skills to the mission; disability of a single person among a small crew could have serious consequences on scientific experimentation, piloting, or, potentially, mission safety itself. Aborting or rescuing a mission would result in extreme delays and cost. For these reasons, the rehabilitation strategy needs to be tailored based on the physical impairment and healing potential in microgravity.

Rehabilitation protocols must also strive to be evidence based. Current recommendations have evolved from extrapolations of terrestrial clinical experience with patients and bed-rest subjects. Research of long-duration space-flight rehabilitation amplifies the difficulties of rehabilitation research seen on Earth: minimal sample sizes (only a few people per year), variable medical and therapeutic interventions, nonstandardized outcome measurements, and limited availability of outcomes because of issues of confidentiality. Simulation studies using Earth-based models to mimic weightlessness (bed rest or water immersion) only capture some of the physiologic adaptations of space travel.
SUMMARY

Astronauts are a unique population of physically and mentally fit individuals who undergo physiologic adaptation during weightlessness, only to find themselves disabled when returning to our normal environment. Countermeasures have reduced but not eliminated impairments to astronauts on landing. As the duration of space flight continues to lengthen, rehabilitation becomes increasingly important. The commonalities between people with physical disabilities treated by physiatrists and astronauts on reentry to gravity support the need for a greater contribution of physiatric expertise to the rehabilitation of astronauts.

Research on the effects of weightlessness and the development of evidence-based rehabilitation protocols are needed, especially for cases of landing on a virgin surface with no ground crew. Efficient space rehabilitation strategies can, in turn, benefit the rehabilitation care of disabling conditions on Earth.

Thus far, humankind has not reached a threshold limit of exposure to weightlessness beyond which the body cannot readapt to Earth. Specific space-flight rehabilitation strategies will help further extend this limit.

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Neuromuscular Electrical Stimulation During Task-Oriented Exercise Improves Arm Function for an Individual with Proximal Arm Dysfunction After Stroke

ABSTRACT


This case report examined the effectiveness of a home program using neuromuscular electrical stimulation (NMES) during voluntary task-oriented exercise to achieve functional and impairment improvements for an individual with primarily proximal arm paresis after a stroke. The subject initially achieved a Fugl–Meyer Assessment (FMA) score of 58/66, but she reported minimal functional use of her involved, dominant arm. The 6-wk intervention consisted of NMES-assisted task practice involving repetitive reaching for and manipulation of small objects for three daily 15-min sessions. The subject applied NMES to the deltoid and triceps brachii muscles to augment shoulder flexion and abduction and elbow extension during task practice. Outcome measures included the FMA, the Action Research Arm Test (ARAT), and the Motor Activity Log Quality of Movement subscale (MAL-QOM). The FMA remained unchanged, but the ARAT and MAL-QOM showed improvements, from the beginning to the conclusion of the intervention, that were maintained at 6-wk follow-up.

Key Words: Stroke, Exercise, Physical Therapy, Electrical Stimulation

Half of the people with poststroke hemiparesis have nonfunctional upper extremities (UE) at 4 yrs after onset. These findings are consistent with the expected pattern of greater distal than proximal weakness in paretic UEs that results in inability to use the hand in functional tasks. However, deviations from this pattern have been demonstrated, highlighting the presence of significant proximal weakness in the UE after stroke and showing that shoulder muscle strength was as strongly associated with UE function as was grip strength.

The intensity or amount of exercise therapy time seems to be a critical factor in interventions shown to improve UE function after stroke. Neuromuscular electrical stimulation (NMES) can be used to produce or augment contractions in paretic muscle. This intervention can be used to assist individuals...
to exercise successfully when nonstimulated exercise is not feasible. To date, positive outcomes using electrical stimulation have been reported primarily in individuals with distal arm dysfunction after stroke.\textsuperscript{7–13} The purpose of this case report is to describe the functional- and impairment-level outcomes of a home program of surface NMES-assisted, task-specific exercise for an individual with proximal UE dysfunction after stroke.

**CASE REPORT**

The subject was a 43-yr-old, right-handed woman who had experienced a stroke 5½ yrs before the current intervention. Magnetic resonance imaging performed after the stroke showed a left-sided intracerebral hematoma in the occipitoparietal region with midline shift. The hematoma was evacuated, and an arteriovenous malformation of the left middle cerebral and left anterior communicating arteries was surgically corrected. The subject participated in inpatient and outpatient physical therapy for 10 mos after her stroke. None of her therapy included electrical stimulation. She was not participating in any formal therapy at the time of the present intervention. Written informed consent was obtained from the subject before participation, in accordance with the university's office for protection of human subjects.

The subject's paretic (right) UE movements were slow. She demonstrated isolated wrist and hand movements but had difficulty combining shoulder flexion or abduction with elbow extension. She reported that she used her nonparetic UE preferentially to meet her responsibilities at home because doing so required less effort and she could move more quickly. The subject's goals were to use her paretic UE more effectively during household and child-care tasks, to return to work as an office manager, and to resume driving.

Three outcome measures were administered before intervention, midintervention, after intervention, and at 6-wk follow-up. The Action Research Arm Test (ARAT)\textsuperscript{14} was used to measure UE function. This test assesses both UEs during performance of 19 tasks involving grasp, grip, pinch, and gross movements. The UE subscale of the Fugl–Meyer Assessment (FMA)\textsuperscript{15} was used to measure control of movement. The FMA consists of 33 items examining both UE movements, reflex activity, coordination and speed. The Motor Activity Log Quality of Movement subscale (MAL-QOM)\textsuperscript{16} was used to measure the subject's perception of the quality of movement of the paretic arm during the performance of 30 activities of daily living (ADL). During a structured interview, the subject rates perception of the paretic arm from no use to normal use. The tester was aware of the subject's participation in the study but was blinded to the specific details of the intervention.

An NMES-assisted practice task was designed to incorporate elbow extension with shoulder flexion and abduction movements, and to make use of the subject's voluntary hand function. The task required her to lift a variety of objects that necessitated different handgrips (paper plate, a pen, and an empty 12-ounce aluminum can) from a table top to a shelf 7 inches above. The shelf was placed in front and toward her involved side, to require her to abduct and flex her shoulder as she extended her elbow. She was instructed to lift the objects in random order, as quickly as possible, to and from the shelf. A Rehabilicare NMIII stimulator (Rehabilicare, Inc., New Brighton, MN) and reusable, self-adhering, 2 × 4-inch pregelled electrodes (Empi Inc., St. Paul, MN) provided stimulation. Two stimulation channels were used, one on the deltoid muscle and one on the triceps brachii muscles. A symmetrical biphasic waveform with a stimulus phase duration of 300 μs and a frequency of 35 Hz was used. Ramp and fall times were each 3 secs.

Three aspects of the application of intervention were tailored to enhance the subject's voluntary effort. First, the subject was instructed to adjust the stimulus amplitude for each session only as high as was necessary to allow her to successfully complete the task. Second, the subject used a hand switch in her nonparetic hand to activate stimulation during the portions of the task for which she required assistance. Third, she was instructed to move as quickly as possible as the amplitude ramped up for 3 secs. This ramp time provided her with gradually increasing assistance as the movement became more difficult because of muscle length and the effects of gravity. The ramping amplitude was provided to increase the ease and speed of movement beyond what was possible without stimulation. The subject was instructed to practice the task repetitively during three 15-min sessions per day, 7 days/wk.

As the subject's performance improved, the practice task was modified to make it more challenging. During the second half of the 6-wk intervention phase, the practice task involved moving objects between the table top and two shelves 12 inches above the table, one toward each side; this increased the excursion of shoulder movement required. New objects were also added, including a heavier plastic plate, a variety of coins, and a glass filled with water. The inclusion of these objects was intended to vary the type of grip and arm position and to increase the amount of force required. Lifting the filled water glass encouraged accuracy and precision to avoid spillage.

The subject completed the 6-wk home-based intervention. She was scheduled for a follow-up
reexamination in 6 wks. She was encouraged to use her paretic UE as much as possible, but no other instructions or exercises were given.

She used a logbook to record that she practiced 92 of the 126 possible sessions, averaging 2.19 of the recommended three daily sessions. The mean session length was 16.75 mins. She did not report any difficulty with electrode positioning or discomfort during stimulation. The subject’s FMA score did not show any change from the beginning to the end of the intervention or at 6-wk follow-up. The total score on the ARAT increased at midintervention and again at postintervention, with the increases maintained at follow-up. Results on the MAL-QOM scale indicated that the subject perceived an improved ability to use her paretic arm at midintervention and after the intervention, with additional improvement noted at the 6-wk follow-up (Table 1).

The subject was contacted 1 yr after the termination of the intervention. At that time, she was working in an office 3 days/wk and volunteering at her children’s school 2 days/wk. She had obtained her driver permit and had begun driver training. She felt she had maintained the gains made during the intervention and that these improvements had helped her make changes in her life.

**DISCUSSION**

At 4 yrs after stroke onset, 67% of persons with UE hemiparesis consider nonuse or disuse of the paretic upper extremity to be a major problem. This is true even for some individuals with good motor function.1 The subject in this case report noted that she was not able to move her paretic, dominant (before stroke) UE fast enough to meet her functional needs, even though she had good hand and wrist function. After a 6-wk, home-based, NMES-assisted training program, the subject demonstrated improvements in a functional performance measure (ARAT) and a self-report of her perception of the quality of movement of her paretic UE (MAL-QOM) that were retained at follow-up. No overall changes were seen in her movement control as measured by the FMA.

Several aspects of the intervention may have contributed to the gains. The subject was able to completely perform the training tasks only when stimulation supplemented her voluntary effort. The success associated with NMES-assisted practice may have contributed to her high degree of compliance with the training program and enabled sufficient practice for functional improvement. The subject’s voluntary participation was also thought to be a key feature of the training. A trend toward functional improvement has been found in studies in which participants were instructed to attempt voluntary contractions with stimulation,17 as well as in studies using electromyography-triggered NMES,18 which requires voluntary contractions. In addition, the training in this case report was structured to provide practice that was both task-specific and random. Task-specific practice has been shown to contribute to enhanced functional carryover,19 especially when manipulation of objects is included.20,21 Random practice, achieved in this study through different objects and multiple trajectories, has been reported to be significantly better than massed practice for the retention of arm function after stroke.22

Two aspects of the intervention were targeted to address the subject’s specific needs. She had identified the slow speed of her paretic UE as a barrier to using this extremity in daily life. She was, therefore, instructed to move as quickly as possible. In addition, it was anticipated that NMES would recruit type II motor units23 that the subject was not able to recruit without stimulation because she had been moving at a slow self-selected speed for several years. Movement speed was one of the items on the FMA that did show improvement from the beginning to the end of the intervention, although the improvement was not retained at follow-up. Perhaps the improve-

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Preintervention</th>
<th>Midintervention (3 wks)</th>
<th>Postintervention</th>
<th>6-wk Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMA score (maximum score of 66), involved/uninvolved UE</td>
<td>58/66</td>
<td>55/66</td>
<td>58/66</td>
<td>59/66</td>
</tr>
<tr>
<td>ARAT score (maximum score of 57), involved/uninvolved UE</td>
<td>38/57</td>
<td>40/57</td>
<td>45/57</td>
<td>45/57</td>
</tr>
<tr>
<td>MAL-QOM mean (SD) score (maximum score of 5)</td>
<td>0.98 (1.42)</td>
<td>2.09 (1.34)</td>
<td>2.78 (0.96)</td>
<td>2.97 (1.1)</td>
</tr>
</tbody>
</table>

FMA, Fugl–Meyer Assessment; UE, upper extremity; ARAT, Action Research Arm Test; MAL-QOM, Motor Activity Log Quality of Movement subscale.
ment was not robust enough to be carried over into her daily life once the intervention stopped.

The subject also demonstrated problems with proximal control at the shoulder, especially when trying to simultaneously extend the elbow and flex or abduct the shoulder. Abnormal coupling of elbow flexion and shoulder abduction torques has been shown to limit arm excursion in persons with poststroke hemiparesis.24 Keller et al.25 have demonstrated that electrically induced contraction of triceps brachii has been used successfully to help individuals overcome these abnormal torque patterns in the UE after stroke. This subject’s tendency to flex her elbow as she elevated her shoulder was addressed by applying NMES to the shoulder flexors and abductors as well as elbow extensors simultaneously within a task that required these motions. Repetitive practice of NMES-assisted antigravity shoulder elevation was intended to increase the proximal torque-producing capabilities required to move the entire limb and to stabilize the distal extremity for function.3

Interestingly, there was a trend that the outcome measure items that required significant proximal strength did not improve, whereas items that required more modest proximal UE strength or distal control did improve. On the MAL-QOM, the subject reported that items such as opening the refrigerator, turning a door knob, and using a key remained most difficult, and she reported the most dramatic improvements in combing her hair, carrying objects from place to place, and donning and doffing shoes and socks. Similarly, items on the ARAT, such as grasping and lifting blocks and balls to shoulder level, did not improve, but manipulating a marble and washer/bolt did improve. Interestingly, FMA items involving shoulder flexion and shoulder abduction to 90 degrees did improve from postintervention to follow-up. It may be that the intensity of the training was sufficient to improve her less impaired distal function but insufficient to strengthen her more paretic proximal musculature to participate effectively in function. These findings are consistent with previous findings of greater gains associated with higher pretreatment motor capacity.10,26

The improvements in function and in the subject’s perception of her paretic UE participation in ADLs notwithstanding, there was no change in her overall FMA score. The test items whose scores did improve seemed to be more related to the task practice than were those items whose scores did not change. For example, items pronation/supination with elbow extension and movement speed improved from the beginning to the end of the intervention, although the improvements were not retained at follow-up. The items shoulder abduction, also improved from postintervention to follow-up. No change was seen in the items shoulder flexion from 90 to 180 degrees and from hand to sacrum. The FMA score gains were offset by a score decrease that reflected hyperactivity in UE deep-tendon reflexes at midintervention that persisted through follow-up. Recent reports in the literature have shown variable effects of electrical stimulation on muscle tone after stroke.26,27 It is not clear why the reflex activity increased in association with the electrically stimulated training in this case, or what the relationship of this increase is to the subject’s ability to move her paretic UE. Perhaps the lack of improvement seen in the FMA scores may also reflect the relatively low sensitivity of the FMA to detect clinically meaningful change in chronic hemiparesis.28

Selecting appropriate outcome measures to detect meaningful clinical change is challenging. Concerns about the validity of the Motor Activity Log have been raised in the literature.29 However, the validity of the MAL-QOM has been supported by significant correlations between pretreatment to posttreatment change scores on the MAL-QOM and accelerometer readings. The internal consistency and responsiveness of the MAL-QOM were also supported.30 These findings support the use of the MAL-QOM as a measure of real-world arm use in conjunction with measures of functional performance and motor control.

CONCLUSION

This case report demonstrates the potential for NMES to enable task-specific practice to improve upper-extremity function in individuals with primarily proximal motor impairments after stroke. Many aspects of the training may have contributed to the subject’s gains, but the intensity of the training may not have been sufficient to completely address the subject’s proximal UE paresis. The FMA may not be responsive enough to detect clinical change in chronic hemiparesis. This case provides the framework for designing a clinical trial to compare NMES plus task-specific training against task-specific training without stimulation.

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Sciatic Neuropathy after Lower-Extremity Trauma
Successful Treatment of an Uncommon Pain and Disability Syndrome in an Adolescent

ABSTRACT


Lower-extremity trauma is an uncommon but reported cause of sciatic nerve injury in children and adolescents. Failure to identify sciatic neuropathy after traumatic injury to the lower extremity may lead to the delayed institution of neuropathic pharmacotherapy, electrodiagnostic testing, physical therapy, and increased risk for the development of complex regional pain syndrome. This article presents a case of an adolescent male with neuropathic pain and weakness in the right lower extremity after traumatic injury. Spontaneous recovery of the injured nerve occurred with early institution of pharmacologic and physical therapies. Operative exploration and neurolysis were considered but were not ultimately necessary.

Key Words: Neuropathy, Trauma, Sciatic Nerve, Pain Management

Sciatic nerve trauma at the level of the buttock and gluteal fold can occur as a result of a variety of mechanisms. The most common mechanism of injury in children has been reported to be as a complication of intramuscular injection.1 Children as young as 7 yrs old have been reported to sustain thigh-level sciatic, tibial, and peroneal nerve lesions during trauma from additional causes including gunshot wounds, laceration, and stretch with or without fracture.2–4

This article presents an adolescent male with neuropathic pain and weakness in the right lower extremity after simultaneous sacral fracture and stretch injury to the sciatic nerve, sustained during motor vehicle injury. Diagnosis and successful treatment by a multidisciplinary team of pediatric subspecialists is described.

CASE REPORT

A 14-yr-old, previously healthy male was struck by an automobile while riding his bicycle; he was dragged underneath the car for 150 feet. He sustained multiple abrasions and lacerations, including a very deep soft-tissue injury to the right buttock, involving the muscle and, possibly, the sciatic nerve, and he required emergency debridement. There was no associated head injury or loss of
consciousness. Computed tomography scan of the pelvis documented what proved to be a stable vertebral fracture in the left hemisacrum. Two days later, the patient reported the new onset of neuropathic pain involving the second and third toes on the right side. The pain intensity was 2 out of 10 on the numeric pain rating scale (NRS). It was constant and described as “pins and needles” sensations and a feeling of “being crushed.” He also had “shooting” (NRS = 9 out of 10) pain that occurred three to four times per day and that lasted from a few minutes to 30 mins. Initially, pain management included high-dose opioids and nonsteroidal antiinflammatory drugs, which provided no relief. The pediatric orthopedic surgeon referred him to the pediatric pain-management specialist 1 mo after his injury. Complaints of constant and spontaneous intermittent pain persisted. The patient required the use of a wheelchair because bearing weight on the right foot was extremely painful. On examination, there were multiple significant abrasions of the right lower extremity that involved the right tibial crest extending from below the patella to the ankle (Fig. 1). There was a right-buttock lesion measuring 11 × 8 cm (Fig. 2). Erythema and edema of the right lower leg and occasional tremors of the right foot were present. There was weakness on thigh flexion, leg extension, foot dorsiflexion, and toe extension. The patient was unable to invert or evert the right foot. This was associated with calf atrophy (Fig. 3). There was hypoesthesia involving the right lateral lower leg, the foot, the fifth toe, and the space between the first and second toes. Allodynia was present in the second and third toes. Ankle jerk reflex was absent on the right side. Concurrent psychological evaluation did not reveal clinically significant levels of anxiety or depression.

The diagnosis of femoral and sciatic neuropathy was tentatively made, with strong consideration given to the development of complex regional

FIGURE 1 Multiple abrasions of the right lower extremity.

FIGURE 2 Right-buttock lesion.

FIGURE 3 Right-sided calf atrophy.
pain syndrome type 2. The nerve injury was considered to be either at the level of the sacrum, buttock, and/or right knee. Treatment of pain with gabapentin was initiated, and the dose was titrated upward. The patient began a vigorous physical therapy schedule. A needle electromyogram was performed 5 mos after the injury. Abnormal spontaneous activity, including positive sharp waves and fibrillations, large-amplitude and long-duration motor units, and reduced recruitment pattern on maximal effort, was recorded in the right medial gastrocnemius, peroneus longus, and biceps short head. Other muscles in the right leg, including the anterior tibialis, vastus lateralis, and gluteus medius, showed no abnormal spontaneous activity, normal motor-unit configuration, and a recruitment pattern consistent with effort. These results were consistent with sciatic nerve injury proximal to the midthigh, and they correlated with the location of the buttock wound. Daily outpatient physical therapy included passive and active range of motion in both lower extremities, desensitization of the right lower extremity, and gait training. The patient achieved an improvement in pain control and strengthening of proximal and distal musculature within 1 mo of the initiation of physical and neuropathic pain therapy. Six months after injury, the dosage of gabapentin was tapered without recrudescence of the patient’s pain. Repeat psychological evaluation showed normal reintegration into family and school activities, with no evidence of posttraumatic stress disorder.

DISCUSSION

The buttock wound, the presence of hypalgesia in a tibial distribution, allodynia in a superficial peroneal distribution, and weakness in the anterior, lateral, and posterior compartments of the leg, were considered in identifying the location and mechanism of nerve injury. It was concluded that the cause was likely to be a stretch or laceration injury to the sciatic nerve. Though the patient had a sacral fracture and soft-tissue injury at the level of the right fibular head, his neurological examination and electrodiagnostic studies did not support nerve injuries solely at these locations. Electrodagnostic studies performed 3–4 wks after injury are extremely useful for delineating the pattern of traumatic nerve injuries. Delayed electrodiagnostic examination is necessary to permit denervation changes to occur in the affected muscles. Additionally, these studies may help to distinguish between decreased motor function attributable to impaired nerve conduction vs. decreased motor activity attributable to pain. Perhaps most important is the sampling of individual muscles to localize the level of nerve injury. In this case, denervation changes within the short head of the biceps indicate a sciatic nerve injury proximal to the distal thigh, because this muscle is innervated by the sciatic nerve in the distal thigh. This finding excludes a peroneal injury solely at the fibular head.

Another diagnostic challenge was distinguishing complex regional pain syndrome type 2 from a painful sciatic neuropathy. Severe pain, allodynia, edema, and erythema were all present in this patient after his injury, but these findings did not spread beyond the confines of the sciatic nerve territory. If they had extended into the distribution of another nerve or even the entire lower extremity, the diagnosis of complex regional pain syndrome type 2 would have been made.5

Psychological consequences of the child after traumatic injury are frequently overlooked. Twenty-five percent of traffic-injured children (n = 102) between 3 and 18 yrs of age are reported to have experienced diagnostic posttraumatic stress disorder. Only 46% sought help of any kind.7 Despite the absence of significant symptoms, the patient underwent psychological evaluation at 1 and 6 mos after injury. Psychological counseling, such as individual or family therapy, is useful for elucidating important precipitating or perpetuating factors and to enhance coping and pain-management strategies. In addition to psychotherapy, biofeedback and relaxation training are considered to be an integral part of treatment for complex regional pain syndrome type 1.8

Physiotherapy of the affected extremity represents the cornerstone of treatment after pediatric traumatic nerve injuries.9,10 Aggressive physical therapy strengthens uninvolved compensatory muscles; it also strengthens involved, partially denervated muscles and maintains the flexibility of totally denervated muscles and joints in preparation for their eventual reinnervation and recovery. Without active use of the affected extremity, deleterious changes such as disuse atrophy, stiffness, and complex regional pain syndrome can occur.

Analgesia is a crucial adjunct to physiotherapy. Standard analgesics such as nonsteroidal antiinflammatory medications and opioids are effective for treating pain from bone and soft-tissue injuries, but they are not first-line agents for neuropathic pain. Frequently described as dysesthetic burning, lancinating, or “pins and needles” sensations, neuropathic pain is related to aberrant somatosensory processes occurring in the peripheral nervous system, central nervous system, or both.11 An extensive adult literature of randomized, placebo-controlled trials supports the use of gabapentin in a variety of neuropathic pain syndromes.12 Pediatric and adolescent case reports and case series have suggested the off-label use of gabapentin when neuropathic pain is present in settings including
Many nerve injuries spontaneously recover without the need for surgical nerve repair; however, surgery is indicated in some circumstances. Sharp, lacerating injuries require immediate surgical repair. Blunt, lacerating injuries—for example, by jagged metal in motor vehicle injury or a lawnmower blade—require surgical repair 2–4 wks after injury to permit margination of devitalized tissue at the nerve stumps. Nerve injuries from compression, gunshot, or traction may require repair after a 3- to 4-month delay.18 These lesions typically do not transect the nerve, resulting in a neuroma-in-continuity, and they often spontaneously recover without the need for surgery. When recovery does not occur after 3–4 mos, open exploration is required to permit nerve-action potential recordings to be performed across the affected nerve segment. Recovery requires the regrowth of axons down the degenerated segment. The amount of time required is variable, but it is roughly equal to 1 mm/day of damaged nerve segment length, increasing distally along the extremity.5 Surgical repair was ultimately deemed unnecessary because the patient demonstrated progressive recovery of his femoral, sciatic, common peroneal, deep peroneal, and tibial nerves.

CONCLUSION

Rehabilitation of the adolescent or pediatric patient presenting with neuropathic pain and motor deficits after traumatic injury include early institution of neuropathic pharmacotherapy, electrodiagnostic testing at 3 wks after the injury, rigorous physical therapy for the prevention of disuse, psychological assessment, and consultation with a peripheral nerve surgeon.

For patients who are severely affected by pain and disability, inpatient rehabilitation and regional anesthetic techniques should be considered.

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Thoracic disc herniations (TDHs) occur infrequently, accounting for fewer than 1% of all spinal disc prolapses. Although most TDHs present initially with radicular pain, others may demonstrate only myelopathic signs and/or, even less often, ipsilateral abdominal muscle weakness.

A 75-yr-old male who had been successfully treated with intermittent split-table pelvic traction for a T12–L1 disc herniation returned a year later with new, abrupt-onset, severe left-flank and abdominal pain. The physical examination revealed a large abdominal-wall hernia (Fig. 1) involving both the left upper- and lower-abdominal quadrants. The straight-leg raising test was unrestricted. Sensory and motor testing and the deep tendon reflexes were all normal.

However, there was a notable reduction in the motor units of the muscular abdominal wall. No long tract signs were observed, and the bowels and bladder were controlled. Electroneuromyography demonstrated 4+ fibrillation and positive waves in the left paraspinal muscle at the T10–T12 levels, without similar findings in the adjacent abdominal muscle. However, there was a notable reduction in motor units in the abdominal musculature.

The peroneal motor nerve conductions were normal. Magnetic resonance imaging revealed a large, left T12–L1 disc herniation (Fig. 2). With persistent pain and associated difficulty in walking, the patient was referred to a spinal surgeon and was restarted on split-table intermittent pelvic traction after thermal therapy.

With continuing conservative treatment, the patient’s pain slowly remitted.

TDHs account for 0.24–0.75% of all disc herniations, with an overall incidence of 1/1,000,000 patients per year. This relative paucity of TDHs has been attributed to the stabilizing influence of the rib cage. When thoracic radicular pain is accompanied by myelopathic signs (i.e., hyperreflexia and Babinski reflexes), they mimic the presence of a spinal cord tumor. Although suggestive, an abdominal hernia in the presence of radicular thoracic pain is not pathognomonic evidence of a TDH. Other sources of thoracic root compromise include, among others, diabetes mellitus and/or viral exanthems (i.e., poliomyelitis), as well as herpes zoster.

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