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Effect of Overground Training Augmented By Mental Practice On Gait Velocity in Chronic, Incomplete Spinal Cord Injury

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Abstract

Objective—To compare efficacy of a regimen combining mental practice (MP) with overground training with the efficacy of a regimen comprised of overground training only on gait velocity and lower extremity motor outcomes in individuals with chronic (> 12 months post injury), incomplete, spinal cord injury (SCI).

Design—Randomized controlled, single blinded, study

Setting—Outpatient rehabilitation laboratories located in the Midwestern and Western United States

Participants—18 subjects with chronic, incomplete SCI

Interventions—Subjects were randomly assigned to receive: (a) Overground Training only (OT), occurring 3 days/week for 8 weeks; or (b) OT augmented by MP (MP + OT), during which randomly assigned subjects listened to a mental practice audio recording directly following OT sessions.

Main Outcome Measures—Subjects were administered a test of gait velocity as well as the Tinetti Performance Oriented Mobility Assessment (POMA), Spinal Cord Injury Independence Measure (SCIM), and Satisfaction with Life Scale (SWLS) on 2 occasions before intervention, 1 week after intervention, and 12 weeks after intervention.

Results—A significant increase in gait velocity was exhibited across subjects at both 1 week post-therapy ($p=0.0046$) and at 12 weeks post-therapy ($p=0.0056$). However, no differences were seen in intervention response at either 1 or 12 weeks post intervention among subjects in the MP + OT versus the OT groups.

Conclusion—Overground training was associated with significant gains in gait velocity, and that these gains were not augmented by further addition of mental practice.

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Keywords

rehabilitation; motor imagery; mental practice; spinal cord injury

Approximately 25% of patients with incomplete spinal cord injury (SCI) remain unable to ambulate independently.¹ Muscular and cardiovascular deconditioning, spasticity, and decreased bone density are commonly associated with compromised ambulation in this group.^{2,3,4,5} As a result, increased ambulation quality and speed are frequent rehabilitative goals.⁶

It is believed that patients with SCI exhibit cortical plasticity in response to repetitive activity.^{7,8} Vertebrate spinal cords also house “central pattern generators” activated by repetitive locomotor activity.^{9,10,11} These mechanisms contribute to increased walking speed observed following overground training.^{12,13,14,15} Whereas compensatory strategies (e.g., braces) increase independence but not active movement, overground training-based strategies attempt to restore walking through repetitive, motor learning-based, physical practice. However, it remains unclear which strategies should be used to best augment and/or maximize the efficacy of overground training. One plausible approach is mental practice (MP) a non-invasive technique during which physical skills are repetitively, cognitively rehearsed. For decades, studies have reported improved motor function when MP is combined with physical practice of the same activity.^{16,17} MP’s application to neurorehabilitation is supported by evidence suggesting that its use activates the same neural areas as physical practice of the same tasks.^{18,19,20} Preserved supraspinal influences after incomplete SCI^{21,22} would likely allow for similar neural activations and adaptive plasticity to occur. Furthermore, MP can be useful when physical practice is difficult (e.g., ambulation)^{23,24,25} and was successfully applied to rehabilitative training in stroke,^{26,27} including several studies targeting ambulation and lower extremity movement.^{26,28,29,30} Thus, this pilot study compared efficacy of an overground training regimen incorporating MP with the efficacy of a regimen comprised only of overground training on gait velocity in chronic (> 12 months post injury), incomplete, SCI. We hypothesized that addition of MP to overground training would cause significantly larger gait velocity changes. To our knowledge, this was the first study examining MP application to individuals incomplete SCI.

Method

Subjects

Volunteers were recruited using advertisements and inservices provided to rehabilitative clinics and SCI support groups in the Midwestern and Western United States. The following inclusion criteria were applied: (1) age 18; (2) incomplete SCI, experienced > 12 months prior to enrollment; (3) manual muscle test score 1–3 in the quadriceps, hamstrings, and hip flexors, and ability to ambulate with at least a minimal assist; (4) range of motion in the lower limbs within functional limits; (5) motor function in at least half of American Spinal Injury Association key lower extremity muscles with strength > 3/5; (6) able to ambulate at least 10 meters with 1 person assistance and/or assistive device; (7) medically stable; (8) stable dosage of antispasticity medications for study duration. *Exclusion criteria* were: (1) score of 3 on the Modified Ashworth Spasticity Scale in the lower extremities; (2) lower extremity pain score of 5 on a Visual Analog Scale; (3) moderate to severe osteoporosis, heterotopic ossification, or fracture history in the lower extremities; (4) enrolled in physical rehabilitation, or other training that could have influenced gait speed; (5) contraindication to magnetic resonance imaging (neuroimaging data were collected as part of this trial in pre-

post fashion and will be described elsewhere). (6) DSM-IV Major Depressive Episode symptom criteria of > 5/9.

Outcome Measures

We used a multimodal measurement approach to discern changes, as was recently advocated.³¹ (a) Decreased walking speed is common after SCI,³² and limits community ambulation.³³ Thus, the primary outcome measure was *gait velocity measured 1 week after intervention*, because it is a robust predictor of community ambulation and function after central nervous system injury,³⁴ including SCI.³⁵ We measured gait velocity using the Gaitrite; a commercially available analysis system that instantaneously measures temporal and spatial gait parameters. Secondary outcomes were: (b) the *Tinetti Performance Oriented Mobility Assessment (POMA)*,³⁶ which measures gait and balance performance during functional activities using a three point ordinal scale (0 = severe impairment; 2 = independence). Item scores are combined into an overall assessment aggregate score (POMA-T) by adding the balance assessment subscore (POMA-B), and a gait assessment subscore (POMA-G). (c) The *Spinal Cord Injury Independence Measure* (SCIM); a SCI-specific measure of disability in 17 domains (e.g., self-care, mobility). (d) To measure how participation in the interventions affected life satisfaction we administered the *Satisfaction with Life Scale (SWLS)*;³⁷ a five-item scale measuring global life satisfaction.

Study Design, Testing, Randomization, and Intervention

A multiple-baseline, randomized, controlled, single-blinded design was used. Two sites located in the Midwestern and Western United States administered the protocol, which was approved by each site's local institutional review boards. Following screening and completion of approved consent forms, instruments were administered twice by a blinded rater at each site, with testing sessions occurring 1 week apart. Following the second testing session, subjects were assigned to a study condition using a computer-generated, random numbers table: (a) overground training augmented by MP (OT + MP); or (b) overground training only (OT).

Overground Training—A variety of overground locomotor training strategies are used clinically to increase gait velocity.³⁸ For generalizability to clinical settings, we used a manual, motor learning-based, regimen administered in ½ hour increments, occurring 3 days/week during an eight-week period. Most sessions began with ≈ 5 minutes of stretching targeting primarily lower extremity muscle groups. Subsequent components (Table 1) emphasized skill acquisition and relearning of motor behaviors comprising ambulation, with the regimen following principles of behavioral shaping described elsewhere.³⁹ The expectation was that repetitive practice of components of ambulation in a part-whole fashion would harness preserved supraspinal networks and neuroplasticity, and facilitate relearning by iteratively redeveloping them across successive trials toward a more functional gait quality and velocity.

Mental Practice Group—Subjects randomly assigned to MP + OT physically and cognitively rehearsed tasks described in Table 1. Specifically, subjects practiced one of the physical practice components during each MP session. Emphasis was placed on not only performing the movements/skills in each of the components, but also on doing so in a functional, patient relevant way (e.g., increasing step length while ambulating in the home). They then listened to the ½ hour MP3 files directly after each physical practice session in an area adjacent to the therapy clinic. MP3 files were regularly rotated so that subjects had mentally rehearsed all exercises shown in Table 1 on three occasions by conclusion of the intervention period. To increase ease of clinical application, MP compliance was noninvasively monitored by: (a) asking subjects about the MP content following sessions

(e.g., “What did you listen to?”) and/or about their experiences (“How was your session?”); and (b) visual monitoring, during which participants were directly observed during MP sessions to assure that they were not performing tasks unassociated with MP participation (e.g., using cellular telephone; sleeping). (c) Additionally, one of the study sites examined the use of chronometry as a MP monitoring technique among subjects enrolled in this trial and other people with SCI, based on the research team’s previous experiences with this monitoring approach.⁴⁰ During chronometry, time taken to mentally and physically perform tasks was timed and compared during the course of specific MP sessions. Chronometry was piloted in this population given the preliminary nature of this trial, with results of this pilot work to be reported elsewhere.

OT Group—Subjects assigned to OT only listened to one of 3 audiotapes directly after therapy in alternating fashion. One sequence provided a progressive relaxation regimen; the second provided information on care after SCI; the third described leg exercises after SCI. Use of a sham intervention and consistent provision of the same OT across groups ensured that both therapy and audio/videotape exposure remained consistent between groups. Thus, the only variable in the study was MP provision.

Post-testing

One and 12 weeks after concluding the intervention, subjects were re-administered all instruments by the same rater who administered outcome measures before intervention. The rater at each site was blinded in that he/she did not know to which group subjects were assigned.

Statistical Methods

The effect of gait training *across all subjects* was evaluated by examining the effect of time using a repeated measures analysis of variance (ANOVA). Analysis of covariance (ANCOVA) models were next used to evaluate treatment efficacy at POST when compared to pre-intervention scores, and adjusting for baseline measures. We chose the ANCOVA model since, unlike crude comparison of post-treatment means, it allows adjustment for baseline and eliminates the possibility of systematic bias. In particular, adjustment for baseline was expected to address possible imbalances in baseline measures and reduce variance in the resulting treatment effect.⁴¹ For the primary outcome of gait velocity in which repeated measures were taken at each time point, further adjustment for intra-patient correlation was made by calculating the Huber/White sandwich estimator of variance. All other outcome measures were measured one time per period. Analyses were performed in STATA Version 11.2 (StataCorp. 2009. *Stata Statistical Software: Release 11*. College Station, TX: StataCorp LP).

Results

Subject Demographics

The final sample consisted of 18 subjects with SCI (10 in the MP + OT group; 8 in the OT only group, Figure 1). A cohort of 6, additional subjects with SCI who met study criteria but received no treatment as well as 16 individuals with no history of neurological injury were both recruited for neuroimaging experiments; their neuroimaging outcomes are reported elsewhere. Characteristics of subjects administered MP + OT or OT are depicted in Table 2. Subject groups did not differ on any demographic variables or in baseline gait velocity. Post-intervention measurements at 8 weeks were available for each outcome for 15 subjects (8 in MP + OT; 7 in the OT only group), due to 3 subjects not returning for follow-up testing.

Outcomes

Across all subjects with SCI, 8 weeks of OT was associated with a significant increase in gait velocity at 1 week ($p=0.0046$) and 12 weeks post-therapy ($p=0.0056$). There were no group differences in gait velocity following intervention (at the POST visit: -8.8 point difference between change scores on average {95% CI: $-25.0 - 7.5$ }, $p=0.27$; at the week 12 visit: -3.9 point difference in change scores on average {95% CI: $-22.1 - 14.3$ }) (Table 3). Similarly, a difference in change from baseline of adding MP to OT was not seen at POST for: (a) POMA-T (Average improvement in MP + OT group over OT alone at POST: -1.0 , 95% CI: $-5.9-4.0$), (b) POMA-B (Average difference between change from baseline scores: -0.9 , 95% CI: $-4.9-3.2$), POMA-G (Average difference between change from baseline scores: -0.4 , 95% CI: $-2.7-2.0$); (c) Total SCIM score (Average difference between change from baseline scores: -1.7 , 95% CI: $-11.9-8.5$), and (d) SWLS score (Average difference between change from baseline scores: -1.8 , 95% CI: $-7.6-4.1$).

Discussion

SCI is a disabling condition that frequently undermines ambulation and independence. A variety of overground training techniques increase gait velocity and reduce disability;^{42,43,44,45} a finding confirmed in the current study across all subjects. However, it remains unclear how to maximize overground training efficacy. This study examined efficacy of mental practice as an adjunctive strategy to motor learning-based, overground training in chronic, incomplete SCI.

Study Limitations and Implications

We hypothesized that subjects assigned to the MP + OT condition would exhibit larger changes in gait velocity than those administered OT only. Our major finding was that neither group exhibited significant changes in any variable, including gait velocity. On the one hand, the results could be taken with caution given the relatively small sample size (which could diminish power to estimate a treatment effect) and the heterogeneity that is common to this population. However, these concerns are somewhat mitigated by the fact that rigorous study criteria were applied, and we used randomized controlled methods to evenly distribute individual characteristics between groups. These factors serve to limit the heterogeneity of the sample; an assertion that is corroborated by the finding that both demographic and outcome measure scores did not differ significantly between groups before intervention, and that both groups exhibited uniform responses to the OT intervention. Furthermore, the sample members were chronic (i.e., many years post injury) and, thus, neurologically stable, meaning that spontaneous neurologic change was unlikely to occur. Given these facets, it is likely that the additive impact of MP is small and, thus, outcomes herein reported are valid.

Numerous OT strategies increase gait velocity,³⁶ making our finding of increased gait velocity following OT unsurprising. An important next question is why addition of MP to OT did not increase OT response. Several explanations seem plausible: (a) the groups were not significantly different at pre-intervention, and randomization evenly distributed subject characteristics. Nonetheless, the MP + OT group scored markedly higher on several outcome variables, and did not exhibit as much change after intervention. Thus, a ceiling effect by this group cannot be eliminated as a possible explanation for the small changes that they exhibited. (b) Pilot work by a member of this team⁴⁶ suggests that patients with chronic SCI exhibit variable cortical activations during imagined and physical foot movements, with decreased magnitude when compared to healthy controls. This finding leaves open the possibility that the MP + OT group required higher durations or frequencies of MP to attain the same benefits as other groups (e.g., stroke). Alternatively, the amount of activation that

individuals attained during MP may not have reached a “critical mass” such that it produced long-term potentiation and/or unmasking of silent synapses.

Conclusion

Results suggest that OT increases gait velocity following incomplete SCI. However, despite previous work suggesting that MP modulates cortical activations in this population, our results suggest that its addition to overground training does not cause additional gait velocity increases.

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The authors certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on them or on any organization with which they are associated AND, if applicable, certify that all financial and material support for this research (e.g., NIH or NHS grants) and work are clearly identified in the title page of the manuscript. There is no drug or device tested herein.

ABBREVIATIONS

SCI	spinal cord injury
MP	mental practice
POMA	Tinetti Performance Oriented Mobility Assessment
SCIM	Spinal Cord Injury Independence Measure
SWLS	Satisfaction with Life Scale
OT	overground training
ANOVA	analysis of variance
ANCOVA	analysis of covariance

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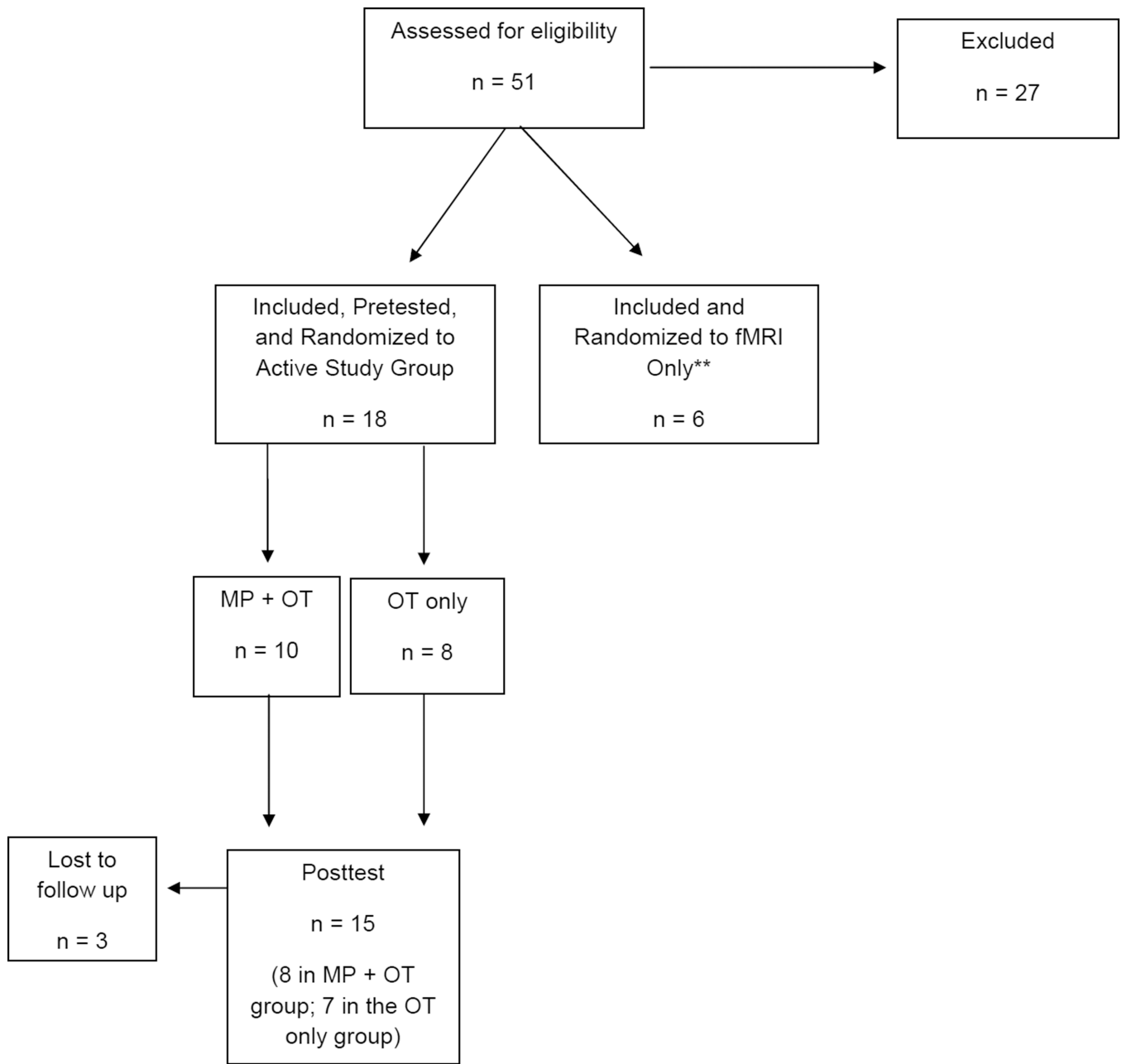


Figure 1. Flow Diagram of Subjects with SCI in the Current Trial
 Note. fMRI data are to be reported elsewhere.

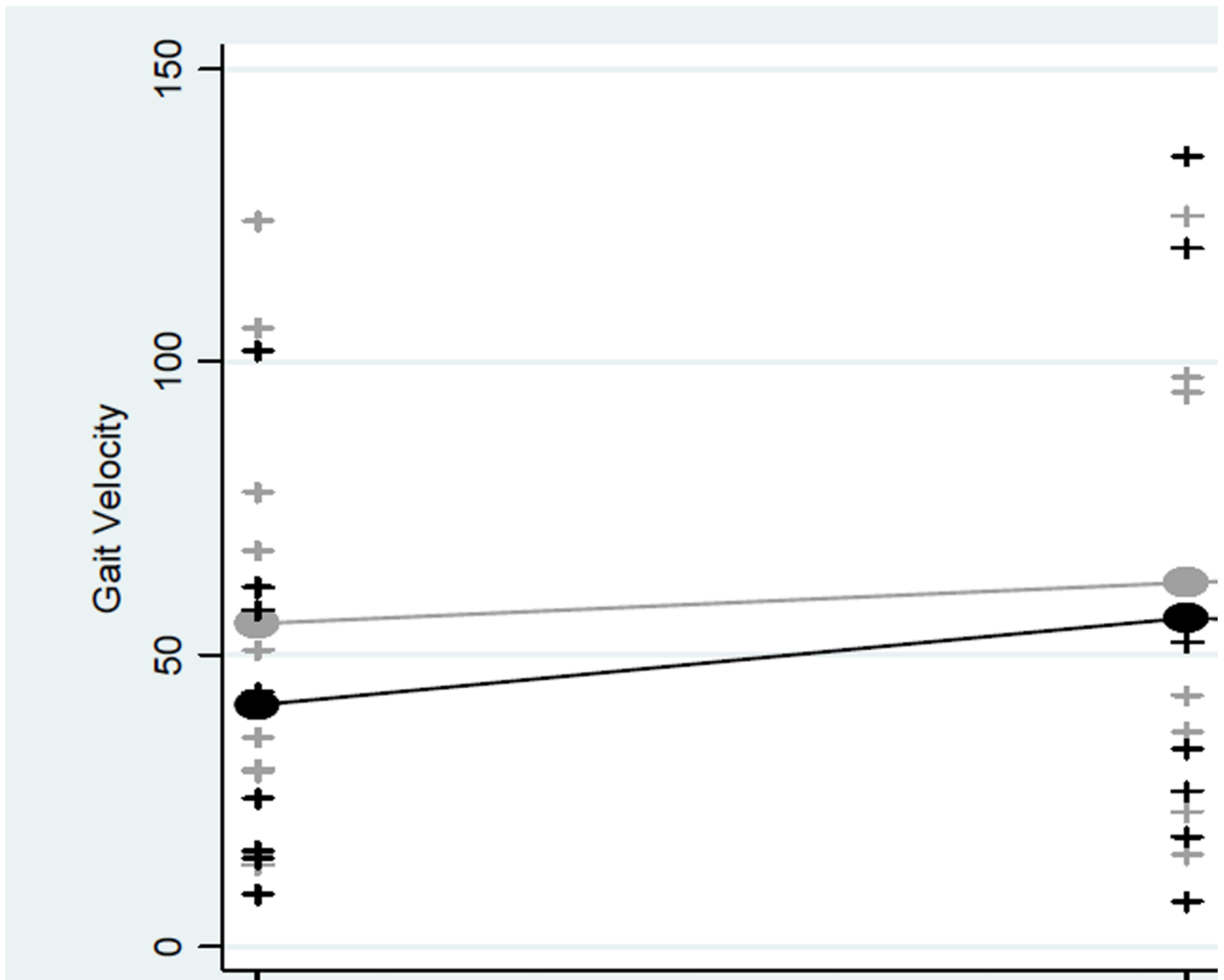


Figure 2. Gait velocity over time by treatment group

Average of replicate measurements from baseline to POST averaged (+) for each participant. Mean velocity at each time (•). MP + OT is depicted group in grey while OT group is shown in black.

Table 1

Description of Overground Training Regimen Components

Gait Training Sessions:	Description	Progressions of the Activity
Timed speed sessions	Subject walks ~10 meters at self-selected speed (as fast as comfortable). Parameters of gait are evaluated qualitatively (visual) and quantitatively (GAITRite)	Speed and distance was augmented based upon individuals' ambulation abilities.
Dynamic balance training	Focuses on dynamic balance training. A full length mirror was used during the exercise as a source of visual feedback.	Static bipedal standing → static unipedal standing → bipedal/unipedal standing on degraded surface. Gradual reduction in base of support, reduction of upper extremity support, and increased duration of each stance was implemented.
Stride and step length (SSL)	Based on the subject's natural step/stride length ascertained at baseline, tape was used to cue where each subject should step in gait training sessions. Parallel bars and lower extremity assistance were used as needed.	Progression was implemented by increasing the distance between steps. Parallel bars were used as assistance to upper extremity if needed.
Cadence	Subjects were asked to match this cadence with help of a metronome. Treatment stressed accuracy of cadence and increased speed of footfalls. Speed expectations and amount of rest were tailored based on each subject's impairment level and cardiovascular and muscular status.	Once the subject was able to ambulate at this cadence with 80% accuracy (8/10 trials) metronome speed was incrementally increased by three beats per minute.
Individual Ankle Joint Movements	Exercises were performed as passive, active assist or active, as appropriate and were intended to improve strength and coordination of the triceps surae, tibialis anterior, peroneals, digitorum and hallucis muscles.	Reducing assistance, increasing effective gravity, and increasing executed range of motion were used to escalate difficulty over sessions. To address the variance in subject abilities, platform height, degree of extremity support, and velocity of motion were varied.
Stepping Up	Subjects stepped up and down onto a firm and vertical surface at least 6" in height. The task was varied depending on ability. Subjects viewed a mirror while performing the exercise.	To address the variance in subject abilities, step height, degree of extremity support, and velocity of motion were varied.
Gait Velocity	Combined all components practiced in earlier sessions into a coherent gait cycle using velocity as a metric.	Speed, distance walked, and level of cueing were individually graded according to subject ability.

Table 2

Characteristics of Enrolled Subjects with SCI

	MP + OT	OT
Total number of patients	10	8
Age		
<i>Mean(sd)</i>	52.3 (11.0)	55.2 (12.5)
<i>Median(min-max)</i>	54.0 (26–63)	59.5 (33–69)
Gender (n(%))		
<i>Male</i>	8 (80)	7 (88)
<i>Female</i>	2 (20)	1(13)
Race (n(%))		
<i>Black/AA</i>	2 (20)	3 (38)
<i>White</i>	8 (80)	5 (63)
Dominant hand (n(%))		
Right	9 (90)	8 (100)
Left	1 (10)	0
Baseline Gait velocity		
Mean(sd)	55.2 (37.8)	41.2 (31.5)
Baseline POMA-T		
Mean(sd)	16.6 (5.7)	15.9 (8.5)
Baseline POMA-B		
Mean(sd)	11.0 (4.4)	9.5 (5.5)
Baseline POMA-G		
Mean(sd)	5.6 (2.6)	6.4 (3.5)
Baseline SCIM		
Mean(sd)	81.8(12.2)	76.3 (11.5)
Baseline SWLS		
Mean(sd)	20.0 (8.5)	20.5 (8.0)

Table 3

Outcome Measure Scores After Intervention By Intervention Group

	Mental Practice <i>mean (sd)</i>	Non-Mental Practice <i>mean (sd)</i>	Difference between Means (95% CI)	Difference between Mean Change Scores (95% CI) *
<i>Gait velocity</i> #				
<i>baseline</i>	55.2 (37.8)	41.2 (31.5)		
<i>6 weeks</i>	62.2 (39.6)	56.2 (50.6)	5.9 (-44.4 - 56.3)	-8.8 (-25.0 - 7.5)
<i>12 weeks</i>	67.6 (47.2)	51.2 (40.6)	16.4 (-34.8 - 67.7)	-3.9 (-22.1 - 14.3)
<i>Total SCIM</i>				
<i>baseline</i>	81.8 (12.2)	76.3 (11.5)		
<i>6 weeks</i>	83.4 (12.4)	78.6 (10.7)	4.8 (-8.2 - 17.9)	-1.7 (-11.9 - 8.5)
<i>12 weeks</i>	85.0 (11.5)	75.1 (8.2)	9.9 (-1.8 - 21.5)	3.9 (-6.6 - 14.5)
<i>SCIM mobility sub-score</i>				
<i>baseline</i>	26.3 (8.9)	25.4 (9.1)		
<i>6 weeks</i>	27.3 (9.7)	24.0 (9.5)	3.3 (-7.5 - 14.0)	0.8 (-4.2 - 5.7)
<i>POMA-B</i>				
<i>baseline</i>	11.0 (4.4)	9.5 (5.5)		
<i>6 weeks</i>	10.6 (4.6)	10.3 (5.1)	0.3 (-5.1 - 5.8)	-0.9 (-4.9 - 3.2)
<i>12 weeks</i>	11.9 (3.4)	10.0 (4.7)	1.9 (-2.9 - 6.6)	1.3 (-2.9 - 5.4)
<i>POMA-G</i>				
<i>baseline</i>	5.6 (2.6)	6.4 (3.5)		
<i>6 weeks</i>	7.1 (3.1)	7.7 (2.1)	-0.6 (-3.6 - 2.4)	-0.4 (-2.7 - 2.0)
<i>12 weeks</i>	7.6 (2.3)	8.0 (2.5)	-0.4 (-3.2 - 2.4)	-0.4 (-2.6 - 1.7)
<i>POMA-T</i>				
<i>baseline</i>	16.6 (5.7)	15.9 (8.5)		
<i>6 weeks</i>	18.1 (6.5)	18.0 (6.9)	0.1 (-7.3 - 7.6)	-1.0 (-5.9 - 4.0)
<i>12 weeks</i>	19.4 (5.4)	18.0 (7.0)	1.4 (-5.8 - 8.6)	0.7 (-5.0 - 6.3)
<i>SWLS</i>				
<i>baseline</i>	20.0 (8.5)	20.5 (8.0)		

	Mental Practice <i>mean (sd)</i>	Non-Mental Practice <i>mean (sd)</i>	Difference between Means (95% CI)	Difference between Mean Change Scores (95% CI) *
6 weeks	20.9 (9.0)	22.1 (8.0)	-1.3 (-10.8 - 8.3)	-1.8 (-7.6 - 4.1)
12 weeks	18.3 (9.7)	24.4 (6.5)	-6.1 (-15.8 - 3.5)	-7.0 (-15.9 - 1.8)

* The treatment effect is the estimated average difference between the mental practice and non-mental practice groups adjusted for baseline values. These estimates were obtained through ANCOVA type regression models.

Since two measures were taken for each time point, the values presented are the mean and standard deviation of the average of the individual measurements for each participant.