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INDIVIDUALS WITH CHRONIC TRAUMATIC BRAIN INJURY IMPROVE WALKING SPEED AND MOBILITY WITH INTENSIVE MOBILITY TRAINING

Abstract

Objective—To determine the feasibility and impact of different dosages of Intensive Mobility Training (IMT) on mobility, balance, and gait speed in individuals with chronic traumatic brain injury (TBI).

Design—Prospective, single group design with 3-month follow-up

Setting—University research lab

Participants—A volunteer sample of 10 participants with chronic TBI (3 months post-TBI, able to ambulate 3.05 m with or without assistance); median age 35.4 (IQR: 23.5, 46) years, median time post-TBI 9.91 (IQR: 6.3, 14.2) years. Follow-up data was collected for all participants.

Interventions—Twenty days (5 days/week $\times$ 4 weeks), 150 minutes/day of repetitive, task-specific training equally divided among 1) balance, 2) gait training, and 3) strength, coordination, and range.

Main Outcome Measures—Pain and fatigue were recorded before and after each session to assess feasibility. Treatment outcomes were assessed before training (pre), after 10 sessions (interim), after 20 sessions (post), and 3 months follow-up and included the Berg Balance Scale and gait speed.

Results—Participants averaged 150.1 (2.7) minutes/session. Median pre-session and post-session pain scores were 0/10 for 20 sessions; median pre-session fatigue scores ranged 0–2.5/10, post-session scores ranged 3–5.5/10. Four outcome measures demonstrated significant improvement pre-test to interim, with 7/10 participants exceeding the minimal detectable change (MDC) for fast walking speed. At post-test, two additional measures were significant, with more participants exceeding MDCs. Changes in fast walking speed and Timed Up and Go were significant at follow-up.

Conclusions—Limited fluctuations in pain and fatigue scores indicate feasibility of IMT in this population. Participants demonstrated improvements in walking speed, mobility, and balance post-intervention, and maintained gains in fast walking speed and mobility at three months.

Keywords

Brain Injury; Mobility; Gait; Dosage

Traumatic brain injury (TBI) is a major cause of long term disability. Over 500,000 individuals are hospitalized every year from a TBI, and over 70,000 people will continue to experience cognitive, physical, and/or behavioral abnormalities following their stay.¹

Conventional rehabilitation utilizes a variety of techniques to address residual motor and gait impairments. While implementing the appropriate techniques is important, implementing them at an appropriate dosage is also imperative. Dosage can be viewed in many ways, but often treatment time/frequency and amount of repetitions are used to describe dosage in the context of physical therapy interventions. Little research regarding physical therapy dosage has been performed with individuals with TBI; however, dosage variables including massed practice, treatment time, and amount of repetitions have been explored in other populations with neurological impairment.²⁻⁵

Recently, a review piece by Bowden et al. (2011) suggested that treatments for individuals with neurological impairments should be multifaceted due to the complexity of movement.⁶ This may be especially true when addressing gait impairments. Deficits in gait following TBI can include slower walking speed, increased double support times, and biomechanical errors that can lead to falls.^{7,8} Looking at the survivors of moderate to severe TBI who return home after rehabilitation, 83% continue to demonstrate deficits in balance and gait that affect their activities of daily living and independence, resulting in greater burden on their caregivers.⁹ Bowden et al. stated that four main areas should be addressed for successful rehabilitation of gait: muscular strength, cardiovascular fitness, dynamic balance, and motor control. Few studies, however, have incorporated all four of these aspects.⁶

Intensive Mobility Training (IMT) is an approach designed to increase dosage and include multifactorial treatments for individuals with gait and balance deficits. IMT utilizes massed practice in an intensive manner to increase the number of functional repetitions an individual performs in an effort to drive motor learning. IMT also employs a variety of training techniques which include: static and dynamic balance activities, gait training, and strength and coordination training. The protocol for IMT was developed over a series of studies involving a variety of populations, including individuals with stroke,^{5, 10} spinal cord injury,^{4, 5} and hemispherectomy.^{5, 11} Participants in these studies performed 3 hours of therapy, 5 days a week for 10 total visits. In the aforementioned populations, the dosage and implementation provided a feasible framework for delivering IMT; however, this format has not yet been proven feasible for treatment of individuals with chronic TBI. The purpose of this study was twofold. The first aim was to illustrate the feasibility of the IMT framework for individuals with chronic TBI. A second aim was to examine if a longer duration of IMT (20 days instead of 10 days) provides greater improvements in gait and balance for individuals with TBI.

METHODS

Participants

Participants were recruited via word of mouth, newspaper announcements, and fliers distributed in the local community. Thirty-one subjects with chronic TBI were screened according to specific inclusion and exclusion criteria. The inclusion criteria required participants to be 18 years of age; 3 months post-TBI with discharge from an inpatient facility; and have the ability to: follow simple three step commands, relay and locate presence of pain, sit independently for five minutes without back or arm support, stand for two minutes with or without the support of an assistive device, and ambulate ten feet

(independently advancing their legs) with max of one person assistance if necessary. Participants were excluded if prior to the TBI they were unable to ambulate 150 feet; had concurrent health problems deemed unsafe by their screening physician to participate; or if they exhibited any of the following: chronic obstructive pulmonary disease, oxygen dependence, severe weight bearing pain, lower extremity amputation, non-healing lower extremity ulcers, kidney disease requiring renal dialysis, legal blindness or severe visual impairments, severe arthritis, knee flexion contracture of $>10^{\circ}$, knee flexion range of motion $<90^{\circ}$, hip flexion contracture $>25^{\circ}$, ankle plantar flexion contracture $>15^{\circ}$, history of deep vein thrombosis or pulmonary embolism, uncontrolled diabetes with recent weight loss, diabetic coma, insulin reactions, uncontrolled seizures, other concurrent neurological conditions, ruptured aneurysm, atriovenous malformation, or pain greater than 5/10 on the visual analog scale.

Evaluation

Prior to participation, all individuals signed an informed consent form approved by the Institutional Review Board at xxx. A physical therapist, who was not involved in delivery of treatment, assessed the participants before they began the intervention (pre-test), after 10 sessions (interim), after 20 sessions (post-test), and at a 3 month follow-up (average time to follow-up was 101.5 (8.48) days). A battery of tests was employed to assess the participants' balance, gait speed, endurance, dual tasking ability with gait, self-awareness, and quality of life. Tests administered include: Berg Balance Score (BBS), Dynamic Gait Index (DGI), Single Leg Stance (SLS), 10 Meter Walk Test – Self Selected Velocity (10SS), 10 Meter Walk Test – Fast Paced Velocity (10F), Six Minute Walk Test (6MWT), 30 Second Sit-to-Stand Test (30SS), Timed Up and Go Test (TUG), Walking While Talking – Average Errors (WWTAE), Walking While Talking – Alternating Letters (WWTAL), Walking While Talking – Average Time (WWTAT), Fall Efficacy Scale (FES), Global Rate of Change Scale (GRoC), and Quality of Life after Brain Injury Questionnaire (QOLIBRI). Information regarding the selected outcome measures is presented in Table 1.

Additionally, pain and fatigue levels were obtained before and after each of the 20 sessions to assess feasibility. Ratings were based on an 11-point visual analog scale with 0 representing no pain or fatigue and 10 representing excruciating pain or extreme fatigue. Number of sessions and hours of intervention completed by each participant were also recorded, as well as any adverse events during the intervention.

Intervention

The participants underwent 20 days of treatment (5 days/week $\times$ 4 weeks), totaling 50 hours of therapy. During each session, participants were required to complete 50 minutes in 3 distinct domains of activities (total 150 minutes/session): 1) gait training with a body-weight supported treadmill system, 2) balance activities, and 3) strength, coordination, and range of motion. Gait training was performed on a treadmill using a protocol adapted from Behrman et al.¹² with the following objectives: 1) approach normal temporal parameters of gait; 2) maintain upright trunk; 3) approximate normal joint kinematics for lower extremity joints; and 4) avoid excessive weight bearing on the upper extremities. If an individual was unable to accomplish these main goals independently on the treadmill, body weight support was

used with percentage of body weight determined in an effort to maximize bilateral limb loading without subsequent knee buckling. If the participant was unable to generate the stepping motions independently, then manual cues were used to assist, as well as verbal/visual cues as needed. Both body weight support and manual cueing were constantly monitored and reduced as appropriate over the course of the intervention.

Overground activities during the course of the study were selected based on participant deficits and tailored to their functional ability. Interventions included: over-ground gait training with and without an assistive device; sit-to-stand activities from various surfaces; stair climbing; balance activities (e.g. tandem, single leg stance, visual occlusion, dynamic balance); tasks focused on addressing proprioceptive limitations; range of motion and strengthening tasks targeting the lower extremities and trunk; and coordination and motor control activities. All activities were delivered using a task-oriented approach,¹³ which focused on variability of practice and the selection of tasks that were directed at underlying impairments and incorporated functional activities. As the participants' performance, fatigue, frustration and interest levels changed, the therapy was modified accordingly. For example, as the participants improved in performance, the complexity and difficulty of the tasks was increased in an attempt to continue to provide a challenge. As they became more successful, the activities were changed in various dimensions, such as adding a time component, increasing the height or distance at which the task was performed, or increasing the pattern complexity. Only the time of the intervention was standardized. All activities were monitored and recorded in a daily activity log. Throughout the sessions, intermittent feedback was given to adjust the participants' movement as well as to acknowledge improvements in their task performance. Vital signs (blood pressure and pulse rate) and perceived fatigue and pain levels were recorded prior to and after each session, and as indicated during the intervention (e.g., during the initial days of treadmill training and overground activities to assess participants' blood pressure and heart rate response to exercise). These measurements were taken to assess the feasibility of this framework. Rest breaks were given as needed; however, each participant had a goal of not exceeding thirty minutes of rest for a given three hour period (a single treatment session) to ensure that 50 minutes of each domain (balance; gait; and strength, coordination, ROM) was completed.

Statistical Analysis

Participant demographics were obtained. Descriptive summaries and plots were produced for the pain and fatigue scores at pre-session, post-session, and daily change from pre to post for each of the 20 sessions. Wilcoxon Signed-Rank tests were calculated for each outcome measure between pre-test and the subsequent interim, post-test, and follow-up measurements to determine if the group demonstrated a significant change from the beginning of the study to those various time points. Number of participants meeting or exceeding published minimal detectable change (MDC) values was determined as well. As MDC is sparsely studied for TBI populations, MDC values for individuals with chronic stroke were substituted (except for the 10 Meter Walk Test).¹⁴ All statistical analyses were performed in R version 2.14.0. As this was an early phase study, no adjustments were made for multiple comparisons. A p-value less than 0.05 was considered to be statistically significant.

RESULTS

Sample Demographics

Of the thirty-one individuals screened, twelve met the inclusion criteria. One person chose not to participate, and another started the intervention but was unable to continue secondary to blood pressure inconsistencies, leaving 10 participants who completed all aspects of the study (n=10).

The median age of the participants was 35.4 (IQR: 23.5, 46) years, and median time since TBI was 9.91 (IQR: 6.3, 14.2) years. Of the ten participants, two were female and eight male; six had sustained left hemisphere lesions and four bilateral hemisphere lesions.

Feasibility

Participants completed an average of 150.1 (2.7) minutes of intervention per day. All participants completed 20 treatment sessions, and no adverse events occurred during the study. Median pre-session and post-session pain scores were 0/10 for all 20 sessions. Median pre-session fatigue scores ranged from 0-2.5/10 and post-session scores ranged from 3-5.5/10 across the 20 sessions (see Figure 1 and Figure 2).

Outcome Measure Analysis

Significant (p-value <0.05) changes were observed in 7 of the 14 outcome measures. Four outcome measures (FES, DGI, 10F, TUG) demonstrated significant change pre-test to interim, six (FES, DGI, 10SS, 10F, TUG, 6MWT) demonstrated significant change pre-test to post-test, and three (10F, TUG, SLS) demonstrated significant change pre-test to follow-up. Only two outcome measures, 10F and TUG, demonstrated significant change between pre-test and all subsequent testing sessions. Outcomes are presented in Table 2. In addition, participants were asked to rate perceived change in functional status over the course of the intervention using the 15 point ordinal GROC scale.¹⁵ Ranging from -7 to 7, positive numbers indicate improvement and negative numbers indicate regression. The participants' median scores were 4 (IQR: 4, 5) at interim, 5 (IQR: 4.3, 5.8) post-intervention, and 5 (IQR: 3.25, 6) at follow-up. On the GROC scale, these scores fall between "Moderately Better" (4 on the scale) and "Quite a Bit Better" (5 on the scale).

Minimal Detectable Change

From pre-test to interim, 7 of 10 participants exceeded the MDC for 10F and one participant exceeded the MDC for TUG. From pre-test to post-test, 8 participants exceeded the MDC for both 10SS and 10F, 6 participants exceeded the MDC for 6MWT, and 5 participants exceeded the MDC for TUG. MDCs were exceeded at follow-up by 6 participants for 10F and by 2 participants for TUG. MDC values for the above outcome measures are: .05 seconds for 10 Meter Walk Test,¹⁴ 36 meters for 6MWT,¹⁶ and 2.9 seconds for TUG.¹⁷

DISCUSSION

Research examining the dosage of massed practiced interventions focused on mobility and balance is limited, especially in the TBI population. A few studies have been performed that

have examined treatment time and the number of repetitions completed during traditional outpatient/inpatient therapy sessions in individuals with stroke and/or TBI,^{2, 3} as these variables are often used to describe dosage in the context of physical therapy interventions. These studies were both observational, however, with no direct manipulation of dosage variables (e.g., time, frequency, duration). IMT is a multifaceted treatment approach that focuses on mobility and balance utilizing a massed practice schedule, and has proven feasibility in individuals with stroke^{5,10} and spinal cord injury⁴ but has not yet been proven feasible for the treatment of individuals with chronic TBI. The primary purpose of this study was to illustrate the feasibility of the IMT framework in this patient population; a second aim was to investigate the impact of dosage of IMT (20 days compared to 10 days) on gait, balance, and mobility in individuals with TBI.

On average, participants were able to tolerate the target treatment time of 150 minutes/session. Each participant was able to complete the full 20 days of intervention with limited changes in pain and fatigue scores, and no adverse events (e.g., falls) occurred, indicating that IMT can be feasibly implemented in this patient population. Additionally, participants demonstrated gains in walking speed, mobility, and balance following IMT. While self-selected walking speed did not significantly improve following 10 days of IMT, participants exhibited a significant change in fast walking speed demonstrating an improved capacity to safely increase their walking speed over a short distance. Furthermore, 70% of the participants either met or exceeded the MDC for fast walking speed at this time point. After 20 days of IMT, significant changes were observed for both self-selected and fast walking speeds, with 80% of participants exceeding the MDC for walking speed at both paces. Additionally, a significant improvement in 6MWT was noted after 20 days of intervention, with 60% of participants exceeding the MDC. These findings indicate that a higher dosage of treatment may be more beneficial for gains in self-selected walking speed and endurance, as improvements in these two variables may directly impact each other.

Participants also exhibited significant improvement in dynamic balance during gait (DGI) and mobility (TUG) following both 10 and 20 days of IMT, with half of the participants exceeding the MDC for TUG at post-testing. Improvements in balance, especially dynamic balance, may also have contributed to increases in fast walking speed following the intervention as participants may have felt steadier walking at faster speeds. Significant improvements in fast walking speed and mobility were still exhibited at the 3 month follow-up, with 60% of participants exceeding the MDC for 10F and 20% exceeding the MDC for TUG. Subjectively, participants reported being more confident in their ability to perform daily activities without falling, as demonstrated by significant changes in Falls Efficacy Scale scores at both interim and post-testing.

Overall, these results demonstrate that individuals with chronic TBI can make functional improvements over time following an intensive, multifaceted intervention, and that additional gains were seen after a higher dosage of therapy. These results complement other published literature highlighting the importance of a multifaceted treatment approach for the recovery of gait and mobility in individuals with neurological impairments.⁶ These findings could help guide clinicians in developing more of a comprehensive, massed practice treatment plan for improving gait and mobility in individuals with chronic TBI. While these

results begin to shed some light on the question of dosage and meaningful changes in mobility and balance in the TBI population, more research needs to be performed examining intensive interventions at different dosages in order to establish more optimal treatment parameters in this patient population.

Study Limitations

Several limitations are present in our study. First, the small sample size (n=10) limits the ability to detect statistical significance, as well as the generalizability of our results. Second, the single evaluator used in this study was not blinded to testing session, which could introduce bias and decrease internal validity, but this was done to avoid inter-rater reliability concerns. Third, while each participant performed approximately 50 minutes of activities in 3 distinct treatment domains, a variety of trainers and therapists were used to deliver the intervention. We also did not monitor activity levels or therapy participation from post-test to follow-up, which could have confounded the results. Lastly, MDC values for stroke were also used for comparison in this study. These values may not directly transfer to individuals with TBI, but were used due to limited research involving MDC data in the TBI population and because our sample primarily presented with hemiparesis.

CONCLUSIONS

IMT is a feasible intervention in individuals with chronic TBI. Functional gains in balance and mobility were seen after both 10 and 20 days of IMT, with gains in fast walking speed and mobility still exhibited at the 3 month follow-up. Future studies incorporating a larger sample size with different dosage parameters need to be performed to help determine the most appropriate dosing schedule of IMT (or other multifaceted, intensive interventions) in this patient population.

Abbreviations

TBI	Traumatic Brain Injury
IMT	Intensive Mobility Training
BBS	Berg Balance Scale
FES	Fall Efficacy Scale
10F	10 Meter Walk Test – Fast Paced Velocity
10SS	10 Meter Walk Test – Self Selected Velocity
6MWT	Six Minute Walk Test
DGI	Dynamic Gait Index
TUG	Timed Up and Go
SLS	Single Leg Stance Test
30SS	30 Second Sit-to-Stand Test
QOLIBRI	Quality of Life after Brain Injury Assessment

GRoC	Global Rate of Change Scale
WWTAL	Walking While Talking Test – Alternating Letters
WWTAE	Walking While Talking Test – Average Errors
WWTAT	Walking While Talking Test – Average Time
IQR	Interquartile Range
MDC	Minimal Detectable Change

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Figure 1.

Pre and post session pain scores are presented in box plots. The median daily score for the participants is represented by the solid black line. The circles represent the outliers. The range lines indicate the limits of the first and third quartile of the interquartile range.

Figure 2.

Pre and post session fatigue scores are presented in box plots. The median daily score for the participants is represented by the solid black line. The circles represent the outliers. The range lines indicate the limits of the first and third quartile of the interquartile range.

TABLE 1

Outcome Measurements and Descriptions

Measure	Assessment	Reliability/Validity
Berg Balance Score ^{18, 19} (BBS)	Balance	Valid and reliable measure for fall risk assessment in individuals with TBI
Dynamic Gait Index ^{18, 20} (DGI)	Adaptation to environment	Valid and reliable measure for fall risk assessment in individuals with TBI
Single Leg Stance ²¹ (SLS)	Balance	Valid and reliable measure for mild TBI; not correlated with high mobility tasks
Ten Meter Walk Test ²² (10SS and 10F)	Self-selected (SS) and fast (F) gait velocity	Valid and reliable clinical measurement for gait speed both for self-selected and fast gait speed
Six Minute Walk Test ²²⁻²⁴ (6MWT)	Endurance	Valid and reliable measurement for cardiovascular endurance for individuals with TBI
30 Second Sit-to-Stand Test ²⁵ (30SS)	Power	Validity and reliability has not been established for TBI
Timed Up and Go Test ²⁶ (TUG)	Speed with upright mobility	Validity and reliability has not been established for TBI
Walking While Talking Test ²⁷ -Average Errors (WWTAE) -Alternating Letters (WWTAL) -Average Time (WWTAT)	Dual-task with ambulation: divided attention with cognitive tasks	Validity and reliability has not been established for TBI, though anecdotally consistently reproducible
Falls Efficacy Scale ¹⁸ (FES)	Self-awareness of safety	Reproducible self-assessment for TBI
Quality of Life after Brain Injury ^{28, 29} (QOLIBRI)	Self-report of perceived quality of life following injury	Reproducible self-assessment for TBI
Global Rate of Change ¹⁵ (GRoC)	Self-report of perceived functional change	Reproducible self-assessment of change

TABLE 2

Outcome Measures Medians and Significance Between Pre-test and Subsequent Testing Sessions

Outcome Measure	Median (Q1, Q3)				P-Value		
	Pre-Test	Interim	Post-Test	Follow-Up	Pre to Interim	Pre to Post-Test	Pre to Follow-Up
BBS	50.5 (41.8, 54.8)	50.5 (45.5, 55)	51 (47, 55.8)	49.5 (44.3, 49.5)	.83	.26	.24
FES	90 (74.5, 98)	95.5 (82.3, 100)	100 (87.3, 100)	93.5 (86.3, 99.8)	.02 *	.01 *	.08
30SS (# of reps)	9.5 (7.3, 13.5)	10.5 (8, 14.3)	11.5 (9, 13.5)	10.5 (7.3, 13.8)	.08	.07	.20
DGI	14.5 (11.3, 20.8)	16 (12.5, 21.5)	15.5 (12, 23)	15 (13, 21.5)	.049 *	.049 *	.09
10SS (m/sec)	.88 (.74, 1.2)	.97 (.78, 1.2)	.99 (.76, 1.2)	.90 (.73, 1.2)	.38	.03 *	.41
10F (m/sec)	1.1 (1.0, 1.5)	1.2 (1.1, 1.6)	1.2 (1.1, 1.8)	1.2 (1.0, 1.7)	.01 *	.01 *	.02 *
TUG (seconds)	12.2 (9.7, 23)	10.5 (9.0, 23)	10 (8.0, 19)	11.5 (9.4, 21)	.01 *	.01 *	.03 *
6MWT (meters)	323 (243, 508)	380 (271, 528)	382 (263, 563)	365 (258, 546)	.16	.03 *	.10
WWTAL	6.0 (4.1, 6.9)	4.75 (4.5, 6.0)	5.5 (5.0, 6.6)	4.0 (3.6, 5.0)	.20	1	.05
WWTAE	.75 (.50, 1.4)	.50 (.12, 2.3)	1.0 (.12, 1.5)	2.0 (.50, 2.4)	.78	.61	.11
WWTAT (seconds)	12.8 (9.2, 21)	12.2 (9.5, 16.8)	12.1 (9.6, 16.6)	13.5 (9.2, 18.9)	.23	.13	.43
SLS (seconds)	9.2 (1.4, 35)	26.3 (2.7, 35)	11.3 (.59, 33.9)	19.2 (2.0, 35)	.40	.67	.04
GRoC	-	4 (4, 5)	5 (4.3, 5.8)	5 (3.3, 6)	-	-	-
QOLIBRI	56.8 [†] (50.5, 63)	-	-	58.8 (49.6, 61.5)	-	-	.88 [†]

Abbreviations: repetitions (reps), meters (m), seconds (sec).

* Indicates measurements are significantly different for this time point ($\alpha=.05$).[†] Initial values taken at baseline instead of at pre-test.