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Original Research—CME

A Comparison of Locomotor Therapy Interventions: Partial-Body Weight—Supported Treadmill, Lokomat, and G-EO Training in People With Traumatic Brain Injury

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Abstract

Background: Literature in the application of gait training techniques in persons with traumatic brain injury (TBI) is limited. Current techniques require multiple staff and are physically demanding. The use of a robotic locomotor training may provide improved training capacity for this population.
Objective: To examine the impact of 3 different modes of locomotor therapy on gait velocity and spatiotemporal symmetry using an end effector robot (G-EO); a robotic exoskeleton (Lokomat), and manual assisted partial-body weight—supported treadmill training (PBWSTT) in participants with traumatic brain injury.
Design: Randomized, prospective study.
Setting: Tertiary rehabilitation hospital.
Participants: A total of 22 individuals with ≥12 months chronic TBI with hemiparetic pattern able to walk overground without assistance at velocities between 0.2 and 0.6 m/s.
Intervention: Eighteen sessions of 45 minutes of assigned locomotor training.
Outcome Measures: Overground walking self-selected velocity (SSV), maximal velocity (MV), spatiotemporal asymmetry ratio, 6-Minute Walk Test (6MWT), and mobility domain of Stroke Impact Scale (MSIS).
Results: Severity in walking dysfunction was similar across groups as determined by walking velocity data. At baseline, participants in the Lokomat group had a baseline velocity that was slightly slower compared with the other groups. Training elicited a statistically significant median increase in SSV for all groups compared with pretraining (Lokomat, $P = .04$; G-EO, $P = .03$; and PBWSTT, $P = .02$) and MV excluding the G-EO group (Lokomat, $P = .04$; PBWSTT, $P = .03$ and G-EO, $P = .15$). There were no pre-post significant differences in swing time, stance time, and step length asymmetry ratios at SSV or MV for any of the interventions. Mean rank in the change of SSV and MV was not statistically significantly different between groups. Participants in the G-EO and PBWSTT groups significantly improved their 6MWT posttraining ($P = .04$ and .03, respectively). The MSIS significantly improved only for the Lokomat group ($P = .04$ and .03). The data did not elicit between-groups significant differences for 6MWT and MSIS. There was less use of staff for Lokomat than G-EO.
Conclusions: Locomotor therapy using G-EO, Lokomat, or PBWSTT in individuals with chronic TBI increased SSV and MV without significant changes in gait symmetry. Staffing needed for therapy provision was the least for the Lokomat. A larger study may further elucidate changes in gait symmetry and other training parameters.
Level of Evidence: II

Introduction

An estimated 1.7 million people sustain a traumatic brain injury (TBI) annually [1]. Previous studies have reported the incidence of motor weakness as 9%-56% after TBI [2-6]. TBI may result in variable degrees of residual functional impairment with a multitude of motor deficits and can present as slower walking speeds, increased double-limb support time, and reduced stride [7,8], Ochi et al [8] reported that survivors of a TBI may have a gait characterized by an asymmetrical pattern with a prolonged stance phase

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and a shorter step length for the less-affected limb. Such impairments can interfere with a person's ability to walk and may create dependency on a caregiver or an assistive device.

Improving walking function is often a key component of the rehabilitation program for a person diagnosed with TBI. To achieve functional walking, the importance of repetitive, task-oriented practice in walking has been recognized and incorporated in the rehabilitation setting. According to Schmidt and Lee [9], motor learning reflects a neural specificity of practice because motor skill acquisition involves the integration of the sensory and motor information that occurs during practice, and ultimately, leads to the sensorimotor solution that results in accurate, consistent, and skillful movements. Rehabilitation based on the concepts of repetitive, intensive, task-oriented training has been shown to be effective.

Research has emerged on locomotor therapy using partial body weight support in persons with TBI [10-13]. This rehabilitative intervention involves supporting part of the patient's weight over a motorized treadmill while clinicians use manual facilitation assistance techniques to produce stepping motions. The therapeutic goals of this approach are to achieve restoration and recovery of walking through the inherent capacities of the spinal and supraspinal locomotor centers [14]. This technique is based on the principle of producing a normal physiological gait pattern, with attention to the ideal kinematic and temporal aspects of gait [15]. Through the remediation of gait impairments over time, the locomotor skills being practiced are anticipated to persist once the individual stops the training. To replicate a normal gait pattern during manually facilitated locomotor training, 1-3 therapists are needed to control or assist with trunk and limb kinematics. Provision of manual assistance during partial-body weight–supported treadmill training (PBWSTT) has demonstrated improved gait kinematics and muscle activation patterns but can be physically taxing on therapists and patients [16]. Consequently, robotic gait devices such as the Lokomat (Hocoma, Volketswil, Switzerland) and GE-O (Reha Technology, Olten, Switzerland) have been developed to assist in this task.

Using the Lokomat, Esquenazi et al [17] compared manually assisted treadmill training and robotic-assisted treadmill training in participants with TBI. The study revealed improved self-selected walking speeds with greater improvement in step length symmetry in the robotic-assisted treadmill training group, although no between-group differences were found. There continues to be limited literature on the effects of various modalities of provision of supported walking training in general and in the TBI population in particular. Specifically, it is not well understood whether different locomotor training systems produce different outcomes in kinematics, walking speed, or endurance for participants with TBI when similar treatment regimens are used. As a result, the goal of this study was to extend the previous comparison [17] between PBWSTT and Lokomat across one more training scheme using an end effector robot (G-EO System) and to further examine changes in spatiotemporal symmetry by use of the 3 different modes of locomotor therapy in persons with TBI.

Methods

The current study is an extension from our previously published study [17] that randomly assigned 16 participants to either the Lokomat or PBWSTT for locomotor therapy via a code generator in Microsoft Excel (Microsoft, Redmond, WA). In the study, training mode assignment was not revealed to participants until the participant consented and baseline testing was complete. Participants were recruited between February 2009 and February 2011. Fifteen participants completed the interventions and finished the study. One participant from the robotic-assisted group withdrew after his eighth training session (due to unrelated eye surgery).

Eight additional participants were enrolled in the current study to train using an end effector robot. Participants were recruited from March 2012 to September 2015. One participant withdrew after his 12th training session because of medical concerns caused by changes in his antiseizure medication. The institutional review board approved this study, and all 24 participants signed an informed consent.

Eligibility criteria were TBI with hemiparetic pattern $\geq$ 12 months; 18-70 years of age; able to walk independently with or without ankle foot orthosis or assistive device at least 10 m; self-selected velocity (SSV) between 0.2 and 0.6 m/s; cardiorespiratory status sufficient to tolerate aerobic exercise; able to attend training sessions 3 times a week for 6 weeks for a total of 18 sessions; and able to follow 2-step verbal commands and communicate discomfort. Adverse events were recorded.

Experimental Design

The mean of at least 2 baseline SSV values for each participant on the electronic Gait Mat II (E.Q., Inc, Chalfont, PA) [18] was used to set the initial treadmill speed for the participant. Before every third training visit, SSV and maximal velocity (MV) were reassessed in the same manner, by asking the participant to walk at their "most comfortable speed" and also to walk "as fast as you can without running," respectively. The training speed of the equipment was adjusted with the following algorithm: if either SSV or MV increased by at least 10% compared with the last assessment, the training speed increased by 10%; otherwise, training speed increased by the greater (%) of the 2; if a decrease in either SSV or MV occurred, no change in training speed was implemented.

Participants in all groups received 18 sessions of training during a 6- to 8-week period, generally 3 times per week. Each training session lasted up to 75 minutes. It consisted of a 45-minute walking training period in all 3 training groups with additional time for setup and posttraining evaluation. The participant was asked to walk on the assigned intervention continuously at the prescribed speed with 10%-20% body weight support. Bilateral handrails were provided for support, but no instructions were given to the participants regarding their use or nonuse. Irrespective of the treatment intervention used, every effort was made to provide similar training time across groups. Overground velocity was measured with an instrumented mat, and the same staff person calculated the velocity change and triggered the training velocity adjustment if needed. Therapists' time was recorded for each session across devices to track staff participation.

Standardized verbal encouragement was provided every 6 minutes throughout the training. If a participant requested a rest break, the physiotherapist (PT) provided verbal encouragement twice and then provided a rest period if needed. The participant rested in the standing position with the harness providing support and then continued with the training session. If the participant was unable to complete the session, the number of minutes of training was documented. Three participants in the Lokomat group were unable to complete the full 45 minutes of their first training session, and 75% of the participants in the G-EO group did not complete at least one training session. Participants in the PBWSTT were able to complete the entirety of each training session with rest periods provided.

Intervention

G-EO Systems

End effector robots are reminiscent of an elliptical trainer that includes a harness for safety and support: the subject's feet are strapped to independent footplates moving along a gait-like trajectory that can be adjusted by the therapist in range and velocity while allowing unconstrained movement of knees and only harness related constrain to the hips. Compared with exoskeletal devices, this may result in a more kinematically variable walking pattern that is less precise; however, suggestions have been made that it may be a more naturalistic approach to gait training [19].

The PT and an aide placed the participant in the appropriate fitting harness while the participants' feet were placed on the end effector robotic foot platforms and secured with a ratchet locking strap snugly adjusted around the shoe. Participants were unloaded by 10%-20% of body weight and the speed of walking was set according to the SSV obtained from ground level walking recorded with the electronic Gait Mat II as described previously. Adaptive force ranged between 20% and 40% to attempt normalization of joint angle displacement with symmetrical motions based on visual assessment. Adaptive force did not change throughout the duration of the study, although the velocity could be adjusted upwards every week on the basis of patient SSV increase during ground walking as measured by the Gait Mat II.

Participants initially were set on continuous passive movement for 1 minute at the beginning of each session, which allowed participants to become acquainted to the machine. After 1 minute on continuous passive movement, the PT selected the adaptive mode. If the participant reached preset threshold, the servomotors of the machine shut down and allowed the participant to move along the set trajectory without assistance [20]. A representative participant setup and training on the G-EO device is shown in Figure 1A.

Lokomat

Only one staff person, the PT, was needed for the Lokomat training. The PT placed the participant in the appropriate Lokomat harness and the robotic orthosis. The device and treadmill started with speed set to the closest 0.022 m/s increment (as allowed by the Lokomat

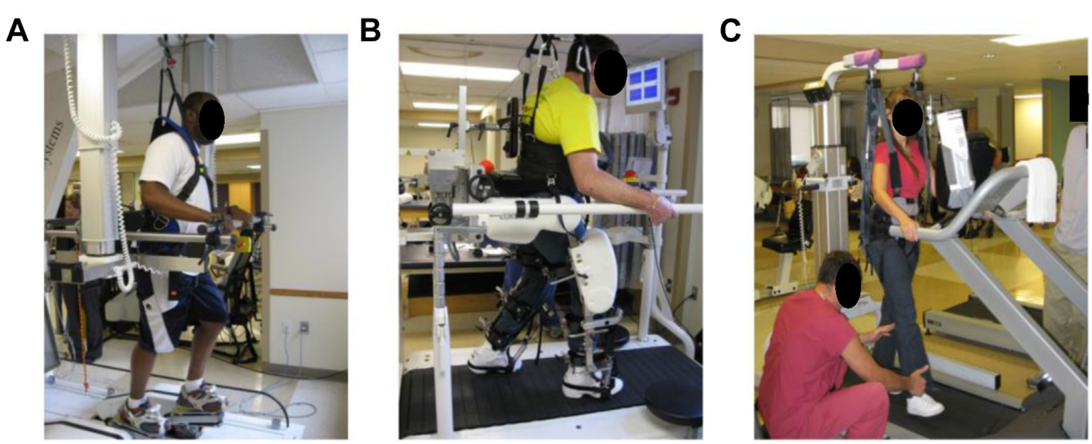

Figure 1. Participants from left to right: (A) G-EO Systems, (B) Lokomat and (C) partial-body weight—supported treadmill training.

device) to the participant's previously calculated training speed. As the participant was lowered onto the treadmill, unweighting was reduced gradually until the Lokomat's dynamic unloading system indicated 10%-20% unweighting. Further setup has been described previously by Esquenazi et al [12]. Figure 1B shows a photographic image of a representative participant setup and training on the Lokomat.

Partial-Body Weight–Supported Treadmill Training

A LiteGait body weight support system (Mobility Research, Tempe, AZ) was used in conjunction with a treadmill. Further setup has been described previously by Esquenazi et al [12]. When the participant was ready, the treadmill started at the closest 0.045 m/s increment (per the treadmill function) to the selected training speed. The PT and/or the PT aide provided manual assistance as needed to participants' lower limbs and/or trunk, with the goal of normalizing the participant's kinematic pattern. The PT and PT aide alternated during the 45-minute training period, allowing for rest periods for them, in view of the high degree of physical demand. A photographic image of a representative participant setup training on the manually assisted treadmill is shown in Figure 1C.

Statistical Analysis

Summary statistics (mean, standard deviation, frequency) were generated for all of the key demographic variables. One-way analysis of variance and χ^2 tests were performed to determine statistically significant differences between the groups at baseline. Wilcoxon signed rank tests were used to determine significant differences from pre- to posttraining for each training group. Kruskal-Wallis was used to determine whether there were significant differences between the training conditions on outcomes: SSV, MV; spatiotemporal asymmetry ratios; and 6-Minute Walk Test (6MWT) and mobility domain of Stroke Impact Scale (SIS). Statistical significance was established at $P < .05$. All statistical analyses were performed with IBM SPSS Statistics (version 19, Chicago, IL).

Effect sizes and percent change were calculated to determine whether a statistically significance difference was of clinical practical importance. Effect sizes were calculated with the following formula: $r = Z/\sqrt{N}$ as the difference between pre and posttest values of the same group. A small effect size was considered 0.1, a moderate effect size was 0.3, and a large effect size was 0.5 [21,22].

Results

Twenty-two participants completed all 18 sessions; 2 participants withdrew from the study for unrelated medical reasons. There were 4 reported adverse events that were study related due to skin irritation and pain. Nine falls occurred at home and were documented as adverse events determined to be unlikely related to the study. We excluded any missing data in the statistical analyses. Demographic characteristics are presented in Table 1. The participants presented with chronic TBI with primarily a hemiparetic pattern. Mean age was similar for the 3 groups. A total of 67% of the participants were men. Right hemiparesis was more common in the G-EO and PBWSTT groups. The hemiparetic side was distributed evenly in the Lokomat group (Table 1). Baseline demographics did not present any statistically significant differences between groups. The studied patient population characteristics were consistent with that reported in national data sets [23].

Temporal and spatial asymmetries were calculated with the following formula:

$$\left|1-\frac{\textit{stance time}\,(\textit{affected})}{\textit{stance time}\,(\textit{unaffected})}\right|$$

$$\left|1-\frac{\textit{step length}\,(\textit{affected})}{\textit{step length}\,(\textit{unaffected})}\right|$$

The greater value of the ratio, the greater degree of the asymmetry.

Differences pre- to posttraining demonstrated a statistically significant median increase in SSV for each of the 3 training groups (G-EO, $P = .03$; Lokomat, $P = .04$; and PBWSTT, $P = .02$) and also for MV for the Lokomat and PBWSTT but not the G-EO group (G-EO, $P = .15$; Lokomat, $P = .04$; and PBWSTT, $P = .03$). There were no pre-post significant differences in swing time, stance

Table 1
Demographic characteristics of all training groups

	G-EO System (n = 7)	Lokomat (n = 8)	PBWSTT (n = 7)	*P* Value
Age, y				.75
Mean ± SD	37.6 ± 10.8	37.13 ± 10.60	43.9 ± 17.0	
Min, max	21, 49	24, 58	24, 69	
Gender, %				.27
Male	85.7	62.5	42.9	
Female	14.3	37.5	57.1	
Injury type, %				.57
Blunt trauma	–	25.0	14.3	
Fall	14.3	–	–	
Gunshot	14.3	–	–	
Motor vehicle accident	71.4	75.0	85.7	
More affected side, %				.59
Left	42.9	50.0	28.6	
Right	57.1	50.0	71.4	

Participants' age was similar in all training groups. More men were presented in the robotic groups, and at least 50% of the participants had right side involvement. In participants in the Lokomat—and only after data collection was completed and analysis performed—we found that the Lokomat group had slower walking velocity at baseline.

time, and step length asymmetry ratios at SSV or MV. Mean rank in the change of SSV and MV were not statistically significantly different between groups, $P = .74$, .66. Mean rank in the change of swing time, stance time, and step length asymmetry ratios at SSV and MV also were not statistically significantly different between groups (SSV: $P = .55$, .14, and .57; MV: $P = .49$, .48, and .13). Changes between and within groups are shown in Table 2. Only the PT was needed for Lokomat training; for PBWSTT, both PT and aide were needed throughout. For G-EO, a PT and aide was required for set-up, but not throughout training.

Differences pre- to posttraining demonstrated a statistically significant median increase in 6MWT for the G-EO and PBWSTT groups ($P = .04$, .03 respectively). Participants in the Lokomat and PBWSTT groups significantly improved their scores on the mobility domain of the SIS ($P = .04$, .03 respectively) but this was not evident for the G-EO.

Discussion

As previously indicated, there is limited literature documenting the effects of robotic-assisted locomotor training in the TBI population. Participants with TBI often exhibit not only pyramidal motor impairment but also major balance and coordination disorders, owing to the mechanism of injury and multilevel cerebellar, vestibular, and sensorial involvement, as well as the potential for deficits due to disconnection syndromes from damage to white matter tracts [24]. Studies on participants with TBI are lacking in the literature, perhaps because such participants are heterogeneous in their clinical presentation, usually presenting both diffuse axonal damage and one or more focal lesions; it is therefore not easy to compare the effects across participants [25].

Also, unlike participants with stroke in whom gait dysfunction more often is due to unilateral hemiparesis/plegia, individuals with TBI may present with para-or tetraparesis/plegia, which may require more complex rehabilitation. Gait performance data from this study are consistent with findings reported in persons with hemiplegic pattern [26]; however, because many individuals with TBI are younger and have less comorbid conditions compared with patients with stroke, they may have potential for greater brain plasticity when exposed to an intensive rehabilitation strategy that may lead to significant beneficial individual and societal effects across their extended lifetimes. The primary purpose of this study was to assess the effects of locomotor training in participants with chronic TBI.

All subjects had a predominant hemiparetic presentation. Table 1 indicates side involved for each group. Of the 24 participants, 22 participants completed the 18 training sessions. The training was well-tolerated by all of the participants, without significant adverse events

Table 2
Data on participants based on training group

	G-EO (n = 7)*					Lokomat (n = 8)					PBWSTT (n = 7)*					Between Group
	Pre	Post	% Change	P Value	Effect Size	Pre	Post	% Change	P Value	Effect Size	Pre	Post	% Change	P Value	Effect Size	P Value
SSV, m/s	0.38	0.46†	21%	.03	−0.57	0.31	0.45†	45%	.04	−0.53	0.37†	0.51	38%	.02	−0.61	.74
MV, m/s	0.69	0.73	6%	.15	−0.37	0.68	0.78†	16%	.04	−0.53	0.68†	0.80	19%	.03	−0.57	.66
STAR	0.15	0.14	−7%	.87	−0.04	0.15	0.13	−15%	.58	−0.14	0.06	0.09	37%	.21	−0.44	.14
SLAR	0.42	0.26	−38%	.24	−0.31	0.48	0.43	−11%	.09	−0.32	0.49	0.34	−31	.55	−0.15	.57
6MWT, m	164.82	191.15	16%	.04	−0.52	168.52	188.25	12%	.21	−0.32	143.71	171.51	19%	.03	−0.57	.97
MSIS	60.23	71.69	19.03	.13	−0.39	65.68	73.18	11.42	.04	−0.53	58.64	70.13	19.60	.03	−0.57	.81

SSV = self-selected velocity; MV = maximal velocity; STAR = step time asymmetry ratio; SLAR = step length asymmetry ratio; 6MWT = 6-Minute Walk Test; MSIS = mobility domain of Stroke Impact Scale.
* Participant withdrawal.
† Statistically significant.

related to the interventions. Participants demonstrated significant gains in SSV and MV posttraining regardless of the intervention with the exception of MV for the G-EO group. In this small sample, differences in spatiotemporal asymmetry ratios were not significantly different pre- to posttraining. Both the G-EO and Lokomat group, however, presented medium effect sizes ($r = -0.31$ and -0.32, respectively) in step-length asymmetry ratio posttraining compared with pretraining. The Lokomat and PBWSTT groups presented medium effect sizes in stance time asymmetry ratio ($r = -0.32$ and -0.44, respectively). The Lokomat group also presented a medium effect size in swing time asymmetry ratio ($r = -0.39$). Although there were no statistically significant values, the effect sizes imply clinical practical significance in asymmetry ratios between pre- and posttraining. Participants in the G-EO and PBWSTT groups significantly improved their 6MWT posttraining. The mobility domain of SIS significantly improved in the Lokomat group post training. The data, however, did not demonstrate any significant differences between groups.

Velocity

Reduced gait speed is a common sequela after TBI, and as such, increased gait speed is one of the main goals for TBI rehabilitation. The amounts of velocity increases varied across devices. The G-EO participants increased their self-selected walking velocity by 21%, the Lokomat by 45%, and PBWSTT by 38% (Figure 2). Perry et al [27] suggested classification of individuals following stroke as "household ambulators," "limited community ambulators," or "full community ambulators" based on self-selected walking speeds of, respectively, <0.4 m/s, 0.4 -0.8 m/s, or >0.8 m/s. Although this classification has not been validated in individuals with TBI, our participants, with a SSV of <0.4 m/s at baseline, were considered "household ambulators." Posttraining, participants in each training group advanced their SSV to the next ambulatory level, "limited community ambulators." Although participants did not advance ambulatory levels based on their MV, there was a mean change from baseline of at least 6%. These findings suggest that with

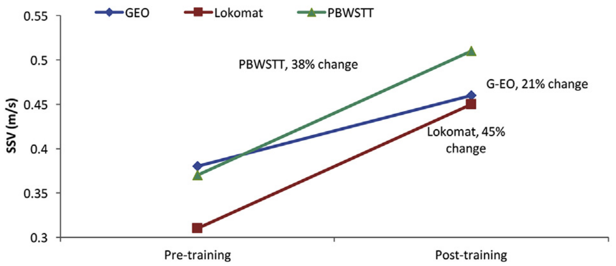

Figure 2. Data on self-selected velocity (SSV). The Lokomat group produced the largest change with a 45% increase in SSV from pre- to posttraining. PBWSTT = partial-body weight–supported treadmill training.

the appropriate gait intervention, individuals with chronic TBI can increase walking function and achieve limited community ambulation.

Gait Symmetry

Although stance time and step length asymmetry ratios did not produce statistically significant results, all training groups showed a decrease in asymmetry ratio (except in stance time asymmetry ratio for the PBWSTT group). The Lokomat and G-EO groups produced moderate effect sizes, which may imply that the robotic devices may elicit more advancement of the paretic limb and therefore produce a more symmetrical gait pattern. Generally, individuals with step length asymmetry tend to present a longer step on the paretic side. Balasubramanian et al [28] investigated the relationship between step length asymmetry and hemiparetic walking performance and concluded that step lengths strongly relate to the propulsive forces generated by the paretic leg specifically subjects generating least paretic propulsion walk with relatively longer paretic steps. The reduction in asymmetry ratio can be attributed to the improvement in nonparetic leg propulsion from the robotic devices training.

Endurance

Walking endurance was measured with the 6MWT and its improvement adjudicated to the participation in an aerobic activity. Consistent with other authors findings [29], individuals with TBI may benefit from an exercise program. Participants in our study generally improved their endurance based on the 6MWT after their training. Each training group showed at least a 12% increase in their 6MWT from pre- to posttraining.

Overall, these results demonstrate that individuals with chronic TBI can make functional improvements after an intensive locomotor training intervention. These findings could assist in the development of clinical guidelines that incorporate massed, task specific practice treatment with the goal of improving gait and mobility in individuals with chronic TBI. The use of robots appears to reduce staff use compared with manual assisted training. More research is needed to examine interventions at different speeds and treatment duration to optimize treatment parameters in this patient population as well as attempts to document the financial impact of the intervention.

Limitations

This study involved a small cohort of participants, which reduced the strength of the statistical power. The lack of randomization for the G-EO group and the small sample size may have affected the results of the study. To represent the wider TBI population performances, we limited the recruitment to slower walking velocity of $\leq$0.6 m/s and those who could walk at least 10m independently with or without a device and/or bracing. Although an increase of no more than 10% on walking velocity was determined in the protocol, the G-EO was able to change velocity by 0.3 m/s, the Lokomat by 0.22 m/s and PBWSTT by 0.1 m/s. This difference may be related to the limitation in walking speed adjustments for the end-effector system used for our study when compared to the other two interventions. Differences may be attributed to the varied speeds used for each intervention.

The maximum speed for each device was not uniform. The maximum speed the G-EO could reach was 2.3 km/h. Because of practical limitations in staff motions assistance for PBWSTT, the maximum speed on the PBWSTT was 2.41 km/h compared with 3.2 km/h for Lokomat and 2.3 km/h mph on the G-EO.

From this study, there is no conclusive evidence that one intervention preferentially results in improved locomotor function but rather of the beneficial impact of participation in such program to increase walking velocity. However, future study on the confounds such as individuals who are unable to walk independently, have faster SSV, or participants' time from injury may provide insights into positioning robotics in the continuum of care. The cost of each form of locomotor training including the staffing required may also play a role in the clinical implementation of these interventions.

Conclusions

This randomized study indicates that task-specific walking training in persons with chronic TBI using manual assisted locomotor training or robot assisted therapy with an exoskeleton or an end-effector robot system produces significant improvements in SSV. Some differences were evident in regards to MV, where gains were made only for the PBWSTT and exoskeleton base interventions (Lokomat), and not for the end-effector device (GE-O).

When we compared the effect on gait symmetry improvements, participants' spatial asymmetry showed a reduction in swing time and significantly improved mobility SIS by exoskeleton based training (Lokomat). Finally, the robotic systems delivered therapy with less staff and likely less staff effort compared with manual-assisted therapy resulting in less staff cost. A clinical trial with a larger sample size may help to reveal further meaningful differences between these three interventions, particularly for spatiotemporal symmetry.

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References

1. Faul M, Xu L, Wald M, Coronado V. Traumatic brain injury in the United States: Emergency department visits, hospitalizations, and deaths. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control; 2010.
2. Walker W, Pickett T. Motor impairment after severe traumatic brain injury: A longitudinal multicenter study. J Rehabil Res Dev 2007;44:975-982.
3. Katz D, Alexander M, Klein R. Recovery of arm function in patients with paresis after traumatic brain injury. Arch Phys Med Rehabil 1998;79:488-493.
4. Black K, Zafonte R, Millis S, et al. Sitting balance following brain injury: Does it predict outcome? Brain Inj 2000;14:141-152.
5. Hillier S, Sharpe M, Metzer J. Outcomes 5 years post-traumatic brain injury (with further reference to neurophysical impairment and disability). Brain Inj 1997;11:661-675.
6. Brown A, Malec J, Diehl N, Englander J, Cifu D. Impairment at rehabilitation admission and 1 year after moderate-to-severe traumatic brain injury: A prospective multi-centre analysis. Brain Inj 2007;21:673-680.
7. Johnk K, Kuhtz-Buschbeck J, Stolze H, et al. Assessment of sensorimotor functions after traumatic brain injury (TBI) in childhood—Methodological aspects. Restor Neurol Neurosci 1999; 14:143-152.
8. Ochi F, Esquenazi A, Hirai B, Talaty M. Temporal-spatial feature of gait after traumatic brain injury. J Head Trauma Rehabil 1999;14: 105-115.
9. Schmidt R, Lee T, eds. Motor Control and Learning: A Behavioral Emphasis. Champaign, IL: Human Kinetics Publishers, Inc; 1998.
10. Peters DM, Jain S, Liuzzo DM, et al. Individuals with chronic traumatic brain injury improve walking speed and mobility with intensive mobility training. Arch Phys Med Rehabil 2014;95: 1454-1460.
11. Esquenazi A, Lee S, Packel AT, Braitman L. A randomized comparative study of manually assisted versus robotic-assisted body weight supported treadmill training in persons with a traumatic brain injury. PM R 2013;54:280-290.
12. Westlake K, Patten C. Pilot study of Lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke. J Neuroeng Rehabil 2009;6:18.
13. Wilson DJ, Swaboda J. Partial weight-bearing gait retraining for persons following traumatic brain injury: Preliminary report and proposed assessment scale. Brain Inj 2002;16:259-268.
14. Behrman A, Bowden M, Nair P. Neuroplasticity after spinal cord injury and training: An emerging paradigm shift in rehabilitation and walking recovery. Phys Ther 2006;86:1406-1425.
15. Behrman A, Harkema S. Locomotor training after human spinal cord injury: A series of case studies. Phys Ther 2000;80:688-700.
16. Williams G, Clark R, Schache A, et al. Training conditions influence walking kinematics and self-selected walking speed in patients with neurological impairments. J Neurotrauma 2011;28:281-287.
17. Esquenazi A, Lee S, Packel A, Braitman L. A randomized comparative study of manually assisted versus robotic-assisted body weight supported treadmill training in persons with a traumatic brain injury. PM R 2013;54:280-290.
18. Taylor A. An instrumental gait mat. Proceedings of the International Conference of Rehabilitation and Engineering; Toronto, Canada; 1980.
19. Mehrholz J, Pohl M, Elsner B. Treadmill training and body weight support for walking after stroke. Cochrane Database Syst Rev 2014;1:CD002840.
20. Esquenazi A, Maier I, Beer S, et al., eds. Clinical Application of Robotics and Technology in the Restoration of Walking. London: Springer; 2016.
21. Rosenthal R. Parametric measures of effect size. In: Cooper H, Hedges LV, Valentine JC, eds. The Handbook of Research Synthesis. New York: Russell Sage Foundation; 1994; 231-244.

22. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates; 1988.
23. National Database: 2016 Profile of People within the Traumatic Brain Injury Model Systems. April 2016 ed. Englewood, CO: The Traumatic Brain Injury Model Systems National Database; 2016.
24. Basford J, Chou L, Kaufman K, et al. An assessment of gait and balance deficits after traumatic brain injury. Arch Phys Med Rehabil 2003;84:343-349.
25. Sacco K, Cauda F, D'Agata F, et al. A combined robotic and cognitive training for locomotor rehabilitation: Evidences of cerebral functional reorganization in two chronic traumatic brain injured patients. Front Hum Neurosci 2011;5:146.
26. Esquenazi A, Hirai B. Gait analysis in stroke and head injury. In: Craik R, Oatis C, eds. Gait Analysis, Theory and Application. St. Louis, MO: Mosby; 1995; 412-419.
27. Perry J, Garrett M, Gronley J, Mulroy S. Classification of walking handicap in the stroke population. Stroke 1995;26:982-989.
28. Balasubramanian C, Bowden M, Neptune R, Kautz S. Relationship between step length asymmetry and walking performance in subjects with chronic hemiparesis. Arch Phys Med Rehabil 2007;88:43-49.
29. Jankowski L, Sullivan S. Aerobic and neuromuscular training: effect on the capacity, efficiency, and fatigability of patients with traumatic brain injuries. Arch Phys Med Rehabil 1990;71:500-504.

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Disclosure

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CME Question

Which outcome measure significantly improved after all locomotor therapy interventions?

a. Self-selected gait speed.
b. Modified Stroke Impact Scale.
c. 6-Minute Walk Test time.
d. Gait symmetry.

Answer online at me.aapmr.org