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Body Weight-Supported Treadmill Training Versus Conventional Gait Training for People With Chronic Traumatic Brain Injury

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Objectives: To compare body weight support treadmill training (BWSTT) to conventional overground gait training (COGT). **Design:** Randomized controlled trial. **Setting:** Residential rehabilitation center. **Participants:** Twenty subjects with chronic traumatic brain injury (TBI). **Intervention:** The BWSTT or COGT for 15 minutes plus 30 minutes of exercise 2 days per week, for 3 months. **Main Outcome Measures:** Functional Ambulation Category (FAC), Functional Reach (FR), Timed Up and Go; gait velocity, step width (BOS) and step length differential using instrumented gait mat. **Results:** Step width approached the norm without between-group differences. Step length differential improved significantly more for the COGT. **Conclusions:** Physical therapy can improve gait for patients more than 6 years post-TBI. The COGT is more effective than the BWSTT for improving gait symmetry during overground walking. **Key words:** *body weight support*, *gait training*, *head injury*, *physical therapy*, *rehabilitation*, *traumatic brain injury*, *treadmill*

A NUMBER of studies have investigated the benefit of gait training on a treadmill with an overhead harness system to provide partial body weight support (BWS) for individuals with neurological dysfunction. This rehabilitation strategy was derived from research showing the effect of suspending spinalized cats in harnesses over treadmills.[1] From his work with spinalized cats, Grillner determined that not only can a reciprocal locomotor program be generated at a spinal cord level by central pattern generators, but also, this pattern can be controlled through sensory input. By pulling the stance leg back with the pelvis stabilized in a harness, the treadmill causes extension to the hip of the weight-bearing leg, which triggers alternation in the reciprocal pattern controlled by the central pattern generator.[2] Barbeau and Rossignol demonstrated that the quality of locomotion in spinalized cats improved if they were provided a locomotor training program of progressively reduced BWS and progressively increased velocity on a treadmill.[3] If the locomotor pattern of a spinalized cat can be improved using body weight support treadmill training (BWSTT), it seems reasonable to

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expect that humans with damage to the brain might benefit from this intervention.

Several studies have found positive carryover of BWS treadmill training to overground walking for individuals with incomplete spinal cord injury; however, most of these studies are lacking a control group.[4-6] While Wernig et al found that functional independence in walking increased more for individuals with incomplete spinal cord injury who received the BWSTT compared to conventional therapy,[7] the control group was drawn retrospectively from chart review. This raises the possibility that other factors might account for differences in their outcomes. Schindl et al reported functional gains in nonambulatory children with cerebral palsy after the BWSTT,[8] but this research also lacked a control group.

Randomized, controlled studies address the value of this intervention for people with Parkinson's disease and stroke. Miyai found that the BWSTT was more effective than conventional physical therapy for increasing gait velocity and stride length for individuals with Parkinson's disease.[9] The Cochrane Collaboration on the effectiveness of the BWSTT has performed a systematic review of the literature for people with stroke including data from 11 trials, with a total of 458 participants; they concluded that there were no statistically significant differences between this intervention and others for walking.[10] However, the authors did report a trend toward the BWSTT being more effective at increasing velocity for individuals with stroke who could walk independently.[10] The lack of significant difference in effect of the BWSTT for people with stroke could be interpreted positively or negatively. While it has not been demonstrated to be better than conventional gait training for people with stroke, it appears to be no less effective, and therefore may be a preferred method in situations where the BWSTT is more motivating to the patient, or less physically stressful to the therapist.

Literature addressing the BWSTT for individuals with traumatic brain injury (TBI) is very limited. Seif-Naraghi and Herman described 2 cases, 1 individual who was 4 years post-TBI and 1 who was 4 months post-TBI, in which the level of ambulatory independence improved after a period of training using BWS and a treadmill.[11] Wilson and Swaboda reported on 2 other cases, 1 who received the BWSTT during acute rehabilitation for TBI and another many years after TBI.[12] These subjects were also receiving extensive inpatient rehabilitation, so it is unclear to what extent the improvements in strength, spasticity, standing balance, and ambulation could be attributed to the BWSTT. No randomized, controlled studies were found of the BWSTT for individuals with TBI.

Several factors may make the BWSTT a more effective intervention than conventional overground gait training (COGT) for individuals with TBI. Before a patient becomes independent with walking, he or she relies on an outside person or device for support. When the therapist is providing support of the patient's body weight, it may be difficult for the therapist to simultaneously provide the skilled guidance needed to enable the patient to walk with an optimal gait pattern. Supporting the patient's body weight may also be physically stressful to the therapist, which may result in the therapist reducing the amount of time the patient spends on gait training. If an assistive device such as a walker or cane is used, that device encourages a compensatory strategy for ambulation that may create undesirable motor habits that are difficult to change as rehabilitation progresses. An advantage of the BWS system is that it allows the therapist to have hands free to assist subjects in normal gait movements in a repetitive, task-specific way.[11] The harness support device provides a safe environment for these task-specific repetitive gait cycles to occur.[11] The harness also provides support in a way that does not generate the compensatory asymmetry and/or forward trunk flexion that patients may develop if they were using a cane or walker.[13] The BWS reduces the demands on muscles, which may enable the patient to work on improving the coordination of the movement while gradually increasing the strength of muscles.[14] The controlled environment may also increase patient confidence by providing a safe way to practice walking.[14] As patients progress, the BWS can be gradually decreased, challenging the patient to assert more postural control and balance.[14]

There is a need for randomized, controlled studies to determine whether the BWSTT results in better outcomes than conventional gait training for individuals with TBI. Despite its potential advantages, the BWSTT requires a substantial investment of time and money. Information about the effectiveness of this intervention for improving gait for people with TBI would help patients, their families, and rehabilitation providers make wiser decisions about how to best utilize available resources.

The purpose of this study is to determine whether gait training with the BWSTT is more effective than the COGT in the chronic TBI population. Our hypothesis is that those with chronic TBI trained to ambulate with the BWSTT will have greater improvement in gait parameters and functional measures than those trained with the COGT.

METHODS

Design

Randomized, controlled allocation was used for this study. Subjects were rated by 2 independent observers on the following gait characteristics: (1) level of gait ataxia, (2) level of assistance needed, (3) assistive device, (4) symmetry of gait, and (5) trunk control. *Ataxiain gait* is defined as staggering, poor foot placement and slow, uncoordinated reciprocal progression of gait.[15,16] The level of assistance was recorded using the functional independence measure (FIM) definitions.[17] In an effort to balance the 2 groups with respect to motor presentation, subjects were paired on similarities of the above 5 characteristics in the above order. Each pair of names was placed in a bowl with the first name pulled assigned to the experimental group and the second to the control group. This random assignment was repeated with each pair.

The independent variable in this study was the method of gait training. The experimental condition was the BWSTT. The control condition was the COGT.

The dependent variables were the pretest-posttest change in performance parameters of gait and balance. Dependent measures were subjects' scores on the Functional Ambulation Category (FAC), the Timed Up and Go (TUG) Test, and the Functional Reach (FR) Test. Also, pretest-posttest changes in the following gait parameters were measured using an instrumented gait mat: velocity, step width, and left-right differential in step length.

Subjects

Twenty participants (14 men and 6 women) with an age range of 20 to 57 years were recruited for this study. All participants were in the postacute phase of rehabilitation for TBI and lived in the same residential rehabilitation facility. Most participants were injured in motor vehicle accidents, one was struck by a train, and one fell from a railroad trestle. Prior to the initiation of this study, most were actively participating in physical therapy 2 times a week for 1-hour sessions. The time since injury ranged from 7 to 23 years ago. The subjects' scores on the Mini-Mental Status Examination, a cognitive screening tool, ranged from 2 to the maximum possible of 30. The mean score for adults over the age of 18 is 28 and a score of 23 or less indicates a need for further assessment.[18] Six subjects in each group scored above 23. The subject who scored 2 had aphasia but was able to express his or her needs and concerns (see Table 1 for demographic information).

Subjects who had gait symmetry deficits and met our inclusion criteria were asked to participate in this study. Gait symmetry deficits were identified by physical therapist (PT) consensus and chart review. Inclusion criteria were as follows: (1) ability to communicate discomfort or needs, (2) ability to stand or walk for 20 minutes regardless of need for an assistive device or physical assistance, and (3) adequate range of motion for functional

Table 1. Demographic information for study subjects*

Subject	Age	Sex	Etiology	Clinical presentation	Years postinjury	MMST
COGT group						
1	42	F	Pedestrian struck by car	Mod ataxia; spastic quadraparesis	13	27
2	51	F	MVA	No ataxia; spastic Mod hemiparesis	21	28
3	34	M	MVA	Severe ataxia; spastic quadriparesis	8	22
4	37	M	MVA	Motor apraxia with HO of joints	17	24
5	53	F	MVA	Mod ataxia	19	26
6	40	M	MVA	Mod ataxia; min hemiparesis	12	26
7	33	M	MVA	Mod ataxia; Severe hemiparesis	15	12
8	39	M	MVA	Min ataxia; Mod hemiparesis	22	22
9	54	M	MVA	Mod ataxia	22	27
BWSTT group						
1	33	M	MVA	Mod ataxia; spastic quadriparesis	6	26
2	35	F	MVA	Spastic mod hemiparesis	13	29
3	21	M	MVA	Severe ataxia; spastic quadriparesis	6	15
4	54	M	MVA	Motor apraxia with HO of joints	14	2 (NA-global aphasia)
5	57	F	MVA	Min ataxia; mod hemiparesis	16	30
6	33	M	Pedestrian struck by train	Mod ataxia; min hemiparesis	14	27
7	43	F	MVA	Mod ataxia; spastic quadriparesis	27	21
8	35	M	MVA	Min ataxia; mod hemiparesis	22	18
9	24	M	MVA	Mod ataxia; min hemiparesis	14	29
10	45	M	MVA	Min ataxia; spastic quadriparesis	19	28

*MMST indicates mini mental status test; COGT, conventional overground gait training; f, female; mod, moderate; MVA, motor vehicle accident; m, male; HO, heterotopic ossification; min, minimal; BWSTT, body weight support treadmill training; and NA, not applicable.

gait. Subjects who had a comorbidity of spinal cord injury were excluded.

Instrumentation

The apparatus used for BWS was the Lite-Gait model LGI-350L* (Fig 1). The amount of BWS by the harness was measured using a BiSym Scale. The BiSym bilateral symmetry scale† measures and displays the amount of weight-bearing load supported in standing and as it changes throughout the gait cycle. The treadmill used was the GaitKeeper 2000L,* chosen because it can be slowed as low as 0.1 m/h and therefore is able to accommodate subjects who are unable to walk at the slowest speed on most standard treadmills.

Gait parameters were collected using the GAITRite Gait Analysis system,† which uses an electronic walkway with sensors in a roll-up carpet 24 inches wide by 144 inches long. As a person walks down the walkway, the system captures the location of applied pressure of each footfall as a function of time. The system is portable so the mat can be rolled out onto any solid level surface. A laptop computer

*Mobility Research, Tempe, Ariz.
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Figure 1. Subject undergoing body weight-supported treadmill training using the Lite-gait Harness and the Gaitkeeper treadmill (http://www.litegait.com).

contains the hardware and software necessary for collecting data from the sensors, processing the data into footfall patterns, and computing the temporal and spatial parameters. It is not necessary to calibrate GAITRite prior to each data-collection session. The sensors are embedded in a mat, and therefore their spatial relations do not change. The system can be used to test patients with or without ambulatory aids, such as crutches, canes, or walkers, which was an important factor for this study. For mild to moderately neurologically impaired subjects, the GAITRite system has an interrater reliability of 0.945 and intrarater (test-retest) reliability of 0.902.[19] The GAITRite was used to measure gait velocity and step length differential, as studies by Ochi[20] and MacFayden[21] have identified slow velocity and asymmetry as common gait problems for people with TBI. Step width was measured because the majority of our subjects had ataxia, and step width has been found to be a primary feature of ataxic gait.[22] An increased step width has been associated with an increased incidence of falls.[23,24]

Several standardized tests were used for the pretest and posttest measurements. The TUG Test measured functional ambulation and ability to transition from sit to stand as well as turn. Both intrarater and interrater reliabilities are very high at 0.98.[25] The FR Test, a test of dynamic standing balance developed by Duncan and colleagues, assesses how far an individual is willing to reach moving to the edges of his or her step width in standing without losing balance. There is a reported intrarater reliability of 0.92 and interrater reliability of 0.98.[26,27] The FAC level was used to determine gait ability as follows.[28]

0 = Patient cannot walk or requires help of 2 or more people.
1 = Patient requires firm continuous support from one person who helps with carrying weight and with balance.
2 = Patient needs continuous or intermittent support of one person to help with balance or coordination.
3 = Patient requires verbal supervision or stand-by help from one person without physical contact.
4 = Patient can walk independently on level ground, but requires help on stairs, slopes, or uneven surfaces.
5 = Patient can walk independently anywhere.

Procedures

Informed consent was obtained. One subject was aphasic and consent was given by the guardian. The subject has in the past demonstrated to the staff an ability to express refusal to participate in undesirable activities, but was a willing participant throughout in this research protocol. Pretesting consisted of the TUG Test, the FAC, the FR, and gait parameters collected using the GAITRite Gait Analysis system. These tests were repeated during the posttest period within 2 weeks following the completion of the intervention. Subjects could rest as long as they needed between tests so that fatigue was not an issue during both pretesting and posttesting. Subjects were provided with approximately the same amount of physical assistance by the same therapist during pretest and posttest while ambulating on the GAITRite mat.

All subjects received gait training interventions 2 times per week for 14 weeks. Every attempt was made to make up missed sessions. All subjects walked a total of 15 minutes during a 30-minute period each session. They were instructed to ask for rest if needed, and when they rested, the clock was stopped. All subjects, regardless of group, received 30 minutes of therapeutic exercise each session tailored to their needs that may have included stretching, strengthening, balance activities, or other functional activities. The relatively small amount of time for therapy per week represents a realistic physical therapy schedule for an individual with chronic TBI.

Conventional overground gait training

Conventional overground gait training consisted of walking on level surfaces with whatever assistive device and level of assistance the PT deemed appropriate. Among the 9 subjects in the COGT group, 5 used a wheelchair as their primary means of locomotion and 4 were independent ambulators (2 wheelchair users ambulated with assistance for brief periods during the day).

Body weight-supported treadmill training

The BWSTT consisted of ambulation on a treadmill using an overhead harness to provide partial BWS. The harness was secured tightly around the subject's lower trunk from just below the greater trochanters to roughly the height of the xiphoid process. Padded straps were secured between the subject's legs not to provide weight-bearing support but mostly as a safety measure since the girdle effect of the harness was intended to support the weight at the pelvis. This positioning of the harness allowed for hip flexion and extension. Once the harness was adjusted securely and the subject was placed on the treadmill, 4 adjustable straps were secured and fastened to an overhead support with propping of the upper trunk as needed.

During the first session, the researchers deweighted the subject by 30%, on the basis of values used in a previous study by Hesse and Bertelt.[29] Visintin and Barbeau discovered that when subjects were deweighted greater than 40% they were unable to get heel strike.[1]

Subjects were then instructed to begin walking for a 15-minute duration. Physical assistance was provided by 1 to 3 therapists to correct gait deviations of the lower extremities and provide weight shifting at the trunk throughout the gait cycle. Only when the subject achieved 10 consecutive heel strikes bilaterally, was the percent BWS decreased in increments of 10% until 10% BWS was achieved. BWS was then decreased in increments of 5%. The starting speed for ambulation on the treadmill was the fastest speed that the subject could tolerate. This was based on the work by Sullivan et al, who concluded that training at normal walking velocity was more effective in improving self-selected velocity than training at speeds at or below the patient's typical overground walking velocity.[30] The speed was increased as tolerated over the course of 3 months. The range of speed was from 0.2 to 2.3 m/h, depending on subject ability. Refer to Table 2, which describes the changes in BWS and speed for the 10 subjects in the experimental group. The fourth column in this table states whether extra propping was used. Three of the 10 subjects were not able to maintain an upright posture within the LiteGait harness and required propping by some other device, such as pillows or towels. Two of the 3 were able to decrease the amount of extra propping needed by the end of 3 months.

Subjects in the BWS treadmill group did not practice overground walking in physical therapy. Among the 10 subjects in the BWS group, 9 used a wheelchair as their primary means of locomotion and 1 was an independent ambulator (5 of the wheelchair users ambulated for brief periods during the day with assistance).

Data reduction and analysis

A few minutes after a subject walks down the GAITRite gait mat, the computer system displays the footsteps that were successfully

Table 2. Parameters of the body weight support treadmill training for each subject

Name	BWS, %	Number of persons assisting	Propping	Speed, m/h
1	30 to 30	3 to 2	No	1.5–2.0
2	30 to 20	3 to 2	Yes	0.7–1.5 (last session)
3	30 to 30	3 to 3	No	0.8
4	30 to 20	3 to 2	No	0.6–1.2
5	30 to 20 (only at last session)	3 to 2	Yes (criss-crossing of straps)	0.5–1.0
6	30 to 5	2 to 0	No	2.3
7	30 to 30	3 to 2	Yes (pillows)	0.3–0.5
8	30 to 20 (only at last session)	3 to 2/3	No	1.4
9	30 to 20	3 to 0	No	1.0–1.4
10	30 to 30	3 to 2/3	No	0.6–0.7

recorded. The pressure applied by an assistive device is also visible on the screen and can be selectively erased using the "footfall editor" so that assistive devices do not interfere with calculations of the temporospatial parameters of gait. In a few cases, subjects stepped off the walkway on 1 or more steps. If this occurred at the beginning or end of a lap down the walkway, the bad data were erased and the computer was instructed to use only the good steps. If there were not at least 3 consecutive good steps, the lap was repeated. During data collection, subjects were required to do as many laps on the mat as were needed to get at least 20 good steps. Subjects were given an opportunity to rest as long as they needed between trials to minimize the effects of fatigue.

The 3 temporospatial variables of gait were calculated by the GAITrite software, averaged across the steps recorded for each lap. The velocity was calculated by determining the distance traveled between foot strikes divided by the time it took to travel that distance. Step width was determined by drawing a line from the center of the heel on one footstrike to the center of the same heel on the next footstrike, and then measuring the perpendicular distance from the center of the heel on the other foot to this line. The step length differential is the difference between right-step length and left-step length. Values of these 3 variables reported for each subject were the average for all the steps collected for that subject.

Paired *t* tests compared pretest values to posttest values to determine any significant change over the course of the intervention for all subjects regardless of group. An analysis of covariance (ANCOVA) determined any significant differences between the experimental (BWSTT) and the control (COGT) groups. Six covariates took into account the variability of the subjects: (1) pretest values on the outcome measures, (2) severity of ataxia, (3) level of functional independence, (4) gait symmetry, (5) degree of trunk control, and (6) assistive device used. Two independent raters scored each subject on the last 5 variables. Pearson correlation coefficients determined whether interrater reliability was acceptable (Table 3). The statistical software package used was version 12.0 of SPSS.*

RESULTS

The gait data collected with the GaitRite system are presented in Table 4. The number assigned to a subject in the control group

*SPSS Inc, Headquarters, 233 S. Wacker Dr, 11th floor, Chicago, IL 60606.

Table 3. Interrater reliability for 5 features of the subjects to be used as covariates

Variable	Interrater reliability
Ataxia	0.813
Functional independence	0.983
Gait symmetry	0.891
Trunk control	0.897
Assistive device	0.994

matching the same number in the experimental group indicates pairs that were identified as similar with respect to ataxia, assistance needed, assistive device, symmetry of gait, and trunk control. The amount of assistance provided was the same on the GaitRite for both pretesting and posttesting.

On the pretest, subjects in both groups walked substantially slower than the norm of 137 cm/s.[31] The mean pretest velocity for the BWSTT group was 32.0 cm/s and for the COGT group it was 39.2 cm/s. The mean increases in velocity were 0.8 cm/s for the BWSTT group and 2.8 cm/s for the COGT group. There was not a significant overall difference in velocity from pretest to posttest ($P = .573$) (see Table 5 for summary of pretest-posttest results for all outcome measures). There was also no difference between groups in the change in velocity ($P = .837$), although a trend toward greater improvement in the COGT group was noted. (See Table 6 for results of ANCOVA comparing the BWSTT to the COGT for all outcome measures.)

On pretest, the mean stride width during walking was 18.1 cm compared to the norm of 8 cm for adult men[32] and 6.9 cm for adult

Table 4. Pretest and posttest values for COGT and BWSTT subjects collected from the instrumented walkway*

	Velocity, cm/s		Step width, cm		Step length differential, cm	
Subject	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
COGT group						
1	7.1	6.7	22.1	23.8	47.2	39.9
2	58.0	53.0	19.6	18.3	9.6	0.9
3	12.5	19.0	8.1	5.0	8.1	6.4
4	12.5	30.7	23.7	18.3	41.3	28.8
5	65.6	88.9	23.6	17.8	2.0	2.8
6	80.5	90.9	17.4	15.6	2.9	2.9
7	12.3	4.9	20.3	8.7	31.8	9.9
8	13.5	39.0	22.1	16.1	29.7	10.6
9	90.4	65.5	6.1	7.2	4.7	9.5
BWSTT group						
1	65.3	46.5	11.11	13.5	5.9	7.7
2	18.0	17.4	11.3	19.1	5.4	11.0
3	28.3	20.2	15.47	10.3	5.3	43.4
4	27.1	34.7	27.4	23.0	28.2	32.9
5	11.7	16.0	23.7	23.6	21.4	25.8
6	74.9	86.6	18.0	16.4	3.0	18.0
7	9.2	7.6	11.5	12.9	15.8	12.0
8	42.4	55.6	22.1	16.2	8.0	9.1
9	24.4	26.9	24.3	22.8	64.9	88.2
10	19.3	16.4	16.1	13.6	3.6	2.3

*COGT indicates conventional overground gait training; BWSTT, body weight support treadmill training.

Table 5. Paired *t* tests determining whether there were significant changes as a result of 3 months of gait training

Outcome measure	*M* (SD) Baseline (*N* = 19)	*M* (SD) After 3-month intervention	Mean difference	95% Confidence interval	*P*
Gait velocity, cm/s	35.4 (27.8)	37.2 (28.0)	1.7	−4.7, 8.1	.573
Stride width, cm	18.1 (6.1)	15.9 (5.5)	−2.2*	−4.2, −0.16	.036
Step length differential, cm	17.8 (18.1)	19.1 (21.1)	1.2	−5.4, 7.9	.703
Functional Ambulation Category	2.4 (1.6)	2.4 (1.5)	0.05	−0.06, 0.16	.331
Functional Reach, inches	5.0 (3.9)	5.6 (4.8)	0.66	−0.16, 1.5	.106
Timed Up and Go, s	68 (60)	57 (48)	−11	−28, 6	.178

*Indicates a significant difference between pretest and posttest.

women.[33] The mean pretest-posttest difference was −1.0 cm for the BWSTT group and −3.6 cm for the COGT group. There was a significant overall pretest-posttest difference, with both groups narrowing their step width (P = .036). There was no significant difference between groups, although there was a trend toward more improvement with the COGT (P = .198).

The mean pretest right-left step length differential was 16.1 cm for the BWSTT group and 19.7 for the COGT group. There was a significant difference between groups in the change in step length differential, with the BWSTT group increasing in asymmetry by 8.9 cm while the COGT group improved with a decrease in asymmetry of 7.3 cm (P = .011).

Table 7 shows the FAC levels, FR scores, and TUG scores at the beginning and at the end of the study. At baseline, FR was 4.4 inches for the COGT group and 5.5 inches for the BWSTT group. The mean FR difference from pretest to posttest for the control group was 0.6 inch and for the experimental group was 0.7 inch. Combining the experimental and control groups, there was a trend toward improvement, but not a significant difference between pretest and posttest values for functional reach (P = .106). There was not a significant difference between the groups (P = .957). Three individuals in each group who had a clinically meaningful increase in functional reach of 2 inches or more.

The FAC levels ranged from 0 through 5 on pretest, with a mean of 2.7 for the COGT group and 2.1 for the BWSTT group. The FAC levels stayed the same for all subjects except for 1 (#7 in the experimental group), who improved from 0 to 1. There was no significant improvement on this measure overall (P = .331), nor were there significant differences between groups (P = .641).

The mean TUG score on pretest was 78 seconds for the COGT group and 60 seconds for the BWSTT group. On average, subjects in the COGT group improved by 15 seconds, and subjects in the BWSTT group improved by 8 seconds. No superiority of one treatment over the other was revealed with this test (P = .872) nor did this test show any overall improvement between pretest and posttest (P = .178).

DISCUSSION

Because the subjects in this study were adults who sustained their brain injuries 7 to 23 years ago, they were not expected to improve from spontaneous recovery or maturation. Improvements could therefore be attributed to the physical therapy intervention. An outcome measure that changed

Table 6. ANCOVA comparing BWSTT to COGT*,†

Outcome measure	Baseline, *M* (SD) COGT (*n* = 9)	Baseline, *M* (SD) BSWTT (*n* = 10)	After 3-month intervention, *M* (SD) COGT (*n* = 9)	After 3-month intervention, *M* (SD) BWSTT (*n* = 10)	Difference of adjusted means	95% Confidence interval	*P*
Gait velocity, cm/s	39.2 (34.0)	32.0 (22.2)	42.0 (32.5)	32.8 (24.1)	1.2	−11.0, 13.4	.837
Stride width, cm	18.1 (6.6)	18.1 (6.0)	14.5 (6.2)	17.1 (4.7)	−2.5	−6.5, 1.5	.198
Step length differential, cm	19.7 (17.8)	16.1 (19.1)	12.4 (13.2)	25.0 (25.6)	−15.6‡	−26.8, −4.3	.011
Functional Ambulation Category	2.7 (1.6)	2.1 (1.6)	2.7 (1.6)	2.2 (1.5)	−0.1	−.3, 0.2	.641
Functional Reach, inches	4.4 (4.3)	5.5 (3.7)	5.0 (5.3)	6.2 (4.5)	−0.03	−1.3, 1.2	.957
Timed Up and Go, s	78 (72)	60 (49)	63 (0.57)	52 (41)	3	−35, 41	.872

*ANCOVA indicates analysis of covariance; BWSTT, body weight support treadmill training; and COGT, conventional overground gait training.

†Covariates included pretest values as well as 5 characteristics of the subjects: (1) ataxia, (2) level of functional independence, (3) gait symmetry, (4) trunk control, and (5) assistive device used.

‡Indicates a significant difference between groups.

significantly for both groups from pretest to posttest was step width during gait that narrowed (approaching the norm) and could be an indication of improved balance. Maki found that a wider step width was not only correlated with fear of falling, but was also a predictor of falls. He hypothesized that while a large step width increases stability during the double support phase of gait, the increased lateral acceleration of the center of mass might decrease stability during single limb support. Maki also suggested that a wider step width could negatively affect balance by causing increased lateral head movement, affecting visual and vestibular input.[24] That our subjects reduced their step width from their initial abnormally high value to a value closer to a normal step width is viewed as an improvement in their gait. This positive result supports the potential value of physical therapy for individuals with disability resulting from a TBI that occurred many years ago.

The results of this study did not support our hypothesis that the BWSTT would result in greater improvements in ambulation than the COGT. In fact, the only significant difference between groups, increased symmetry for the COGT group and decreased symmetry for the BWSTT group, suggests that the BWSTT may not be as effective as the COGT for this population. The fact that symmetry of overground walking was worse after the BWSTT is particularly interesting because Hassid et al reported that gait symmetry improved for people with stroke while they were walking on the treadmill with BWS.[34] However, posttest measurements in Hassid's study were taken on the treadmill. Our posttest measures were overground. (We did not measure symmetry of gait while our subjects were on the treadmill with the assistance provided during the BWSTT.) Although the subjects in our study did appear to be walking more symmetrically on the treadmill than they had on pretest overground measures, any improved symmetry did not carry over to overground walking.

Ambulating for 15 minutes, twice a week for 3 months for the BWSTT group, may have been too short a time period to learn a new

Table 7. Scores for Functional Ambulation Category (FAC), Functional Reach (FR), and Timed Up and Go (TUG) pretest and posttest*

	Functional Ambulation Category		Functional Reach, inches		Timed Up and Go, s	
Subject	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
COGT group						
1	2	2	0	0	113	114
2	4	4	8.7	10.8	18	21
3	1	1	0	0	41	36
4	4	4	5.8	3.3	78	53
5	2	2	6.3	8.8	17	13
6	5	5	9.3	10.7	10	9
7	1	1	0	0	128	91
8	1	1	0	0	70	81
9	4	4	9.3	11.3	23	26
BWSTT group						
1	2	2	6.0	9.5	42	36
2	4	4	7.5	7.7	107	58
3	0	0	0	0	38	58
4	2	2	3.0	0	33	36
5	3	3	6.3	7.1	64	49
6	5	5	9.3	10.5	11	12
7	0	1	0	0	90	95
8	2	2	11.0	10.3	22	19
9	2	2	7.7	10.2	18	13
10	1	1	4.0	6.7	58	68

*COGT indicates conventional overground gait training; BWSTT, body weight support treadmill training.

walking pattern when considering that the subjects are 7 to 23 years postinjury. It is possible that more intervention time was needed to benefit from the BWSTT and for improvements gained on the treadmill to transfer to overground walking. Ideally, to achieve carryover from walking with the support of a harness to walking without the harness, the patient would be gradually weaned off the BWS. The criterion of deweighting according to the protocol of 10 independent heel strikes bilaterally was not strictly adhered to in a timely manner for 4 of the subjects. None of our subjects were fully weaned off BWS by the end of just 3 months.

The relation between speed and BWS complicated the procedure. In an effort to maintain the fastest speed tolerated, we may have sacrificed some subjects' ability to achieve the 10 heel strikes bilaterally needed to decrease BWS.

A limitation of this study was that for the 4 subjects whose BWS was not decreased at all, perhaps because of their level of spasticity or to our effort to maintain the fastest speed tolerated, there was a lack of progression of decreasing BWS and trunk control was not practiced.

Specificity of training may explain why the COGT was more effective than the BWSTT. The COGT group ambulated overground with physical assistance provided solely by therapists. Those in the BWSTT group, however, received physical assistance from the harness

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to provide trunk stability, from the treadmill to extend the stance leg, and from therapists to perform other lower extremity movements critical to gait. As the pretest and posttest measures were taken overground, the COGT group ambulated in nearly the same manner during treatment sessions as in the testing sessions. Those in the BWSTT group, however, ambulated in a very different manner during the treatment sessions (ie, over a treadmill with a harness and grab bars) as compared to pretest and posttest measures during which they ambulated overground and with an assistive device. From this point of view, it is not surprising that there was better carryover from any gains made in the COGT to performance on the posttest.

Another possible explanation for the greater improvement in gait with the COGT than the BWSTT was the degree to which subjects were actively engaged in controlling their gait during the treatment sessions. Subjects in the COGT group were given tactile and verbal cues designed to engage active participation of the subject in maintaining good trunk alignment as well as controlling leg movement. Subjects in the BWSTT group were encouraged to actively control their leg movements, but if they did not, then the treadmill and physical assistance provided the movement. The therapist using the COGT could wait for the subject to respond to the cues, but for subjects in the BWSTT group, the treadmill did not wait, so there was a greater chance that the treadmill and therapist passively moved the subjects' legs. Also, the harness provided so much trunk support that it was difficult for subjects to be actively engaged in trunk control. Therefore, the BWSTT may have resulted in a more passive adaptation, with less actual learning. Perhaps decreasing BWS at regular intervals as opposed to meeting the set criterion would have more actively engaged the trunk, allowing for more practice of trunk control.

It was anticipated that the BWS system would impose less physical stress on the PTs than conventional gait training. Ironically, the therapists who participated in this research reported that squatting on the floor and guiding the subject's legs through the gait cycle was more stressful than supporting the subject's body weight during conventional gait training. The increased stress could be attributed partly to the novelty of the positions and repetitive movements the therapist is required to perform during the BWSTT. Raising the treadmill to a better ergonomic height might have made this less physically stressful for the therapists.

The BWSTT requires not only an initial financial investment in the equipment, but also an investment in greater manpower to implement the intervention. Two to 3 therapists were required to assist each patient during the BWSTT compared to only 1 to 2 therapists for conventional therapy. The increase in manpower was necessary to be consistent with previous research studies with the BWSTT in which manual assistance was provided.[8,12,14] Manual assistance corrected for gait deviations at each extremity as well as weight shifting as needed.

There were some limitations of this study related to implementing the protocol for the BWSTT group. The decision regarding when to increase speed of the treadmill was subjective, on the basis of the therapist's judgment of the subject's ability. Also, the harness system was not optimal. The bottom-most straps were secured tightly just below the greater trochanters. This allowed hip flexion and extension, but may have prevented the full range of hip motion needed for a more normal gait pattern or to trigger alternation in the reciprocal pattern controlled by the Central Pattern Generators. Another problem was that the harness tended to slide upward on subjects as they walked, no matter how tightly it was secured. As the harness slid up, it was difficult to maintain the predetermined amount of BWS.

One limitation related to our subjects was the small sample size, especially given the wide variety of clinical presentations included. The population of individuals with TBI is heterogeneous, a fact we tried to address by creating matched pairs according to clinical presentation before randomly assigning 1 member of the pair to each group.

Although we addressed levels of ataxia and hemiparesis versus quadriparesis, we did not objectively measure tone, which is defined as resistance to passive movement. Measuring tone according to (perhaps) the Modified Ashworth Scale[35] may give objective measurements to consider for inclusion criteria for future studies. It is very possible that patients with some types of clinical presentation will benefit more than others from the BWSTT. Future research should include larger groups of homogeneous subjects to determine if this intervention is better suited to individuals with certain clinical presentations.

Another limitation of the study was that the raters of the FAC, FR, and TUG were not unaware of group assignment. Scores on these tests, therefore, may have been biased. However, gait velocity, stride width, and step length differential were measured using an instrumented gait mat, and the data were reduced by a research assistant unaware of group assignment. Stride length differential, the outcome that was significantly different between the 2 groups, and stride width, the outcome that improved significantly across both groups, were measured by naïve raters.

Future research should provide a longer intervention period to allow subjects the opportunity to be weaned off the external support for greater carryover to overground walking. Additionally, more sensitive outcome measures of balance and gait are needed to detect changes (eg, Berg Balance Scale[36]) as well as objective measures to capture changes in walking endurance and cardiovascular changes that might result from participation in an aerobic exercise program. A larger sample consisting of subjects with more homogeneous clinical presentations may help determine which patients would benefit from the BWSTT. Additionally, the order of progression that takes into account the complex interrelationship between increasing speed and decreasing BWS should be more clearly delineated.

CONCLUSIONS

In this randomized, controlled trial, the BWSTT was not found to be more effective than the COGT when provided more than 3 months to individuals greater than 6 years post-TBI. On the contrary, gait symmetry improved more in the COGT group. Three months of physical therapy exercises tailored to the individual's needs, along with either the BWSTT or COGT, resulted in a narrower step width (approaching the norm) during ambulation for individuals with chronic TBI. Gait velocity and FAC did not change significantly for either group after only 3 months of intervention. Further research is needed to determine if a longer intervention period would produce different results.

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