**Locomotor Training for the Brain Injury Population**

Brain injury is a diagnosis more common than one might think. Every 15 seconds, someone sustains a brain injury in the United States1. The prevalence is greater than both breast cancer and AIDS1. Because the brain is the control center for the body, the effects of injury to this area can be very serious and enduring. In fact, one out of every fifty people in America is living with disabilities related to a traumatic brain injury (TBI)1. There is an evident need for research that focuses on the physical and neuro-motor impairments associated with TBI. Most of the current research involves the categorization and treatment of behavioral and cognitive deficits. Presentation following a brain injury is highly varied; however, patients tend to experience paresis, abnormal muscle tone, ataxia, abnormal movement synergies, and postural instability2,9.

Because the brain is the computer of the body, it is responsible for the full gambit of functions. When an injury to the brain occurs, the resulting impairments depend largely on the areas of the brain affected. For example, injury to the frontal lobe of the cerebrum may result in movement impairments or difficulty with planning, reasoning, speech, problem solving, and emotions3. Injury to the parietal lobe will generally cause deficits in movement, recognition, orientation, and perception3. Visual processing will be affected if injury occurs to the occipital lobe and impairment of recognition of auditory stimuli is expected with injury to the temporal lobe3. Injury to the cerebellum often results in difficulties with balance, coordination, and body control3. Injury to the brainstem is associated with deficits in attention, alertness, and awareness3. The brain stem also controls functions of the body that are vital for life such as blood pressure, heart rate, respiration, and digestion3. Each of these factors is necessary for the functional ability to safely ambulate, which makes gait training one of the most important aspects of rehabilitation9. As noted by the long list of potential impairments, the TBI population can be very heterogeneous in presentation, making research regarding motor deficits and treatment difficult to be applicable across the board. This explains the paucity of available research on gait training for the TBI population. The purpose of this review of the literature is to investigate the most beneficial methods of gait training in order to optimize the process of rehabilitation in the post-acute phase of treatment. This review will highlight the importance of task-specific practice, evaluate the current treatment options for gait training, and discuss the most reliable outcome measures available for effectively finding improvements in patient function.

Gait training is an essential part of the process of rehabilitation for more reasons than simply improving functional abilities. Aerobic activities, specifically ambulation, have been shown to improve learning capacity and memory, protect against ischemia or neurotoxicity, and improve mood and mental health4,5,6,7. In a study done by Dishman et al, mice and rats post middle cerebral artery (MCA) cerebral vascular accident (CVA) were studied after an exercise program consisting of treadmill training4. The authors concluded that gait training increased the expression of genes that encode for brain neurotrophins such as brain-derived neurotrophic factor (BDNF). BDNF was found to encourage development of new neurons in the hippocampus, thereby increasing one’s capacity for learning new things and remembering them4. These effects were observed after just one week of gait training4. Gait training was also shown to increase one’s general state of health and reduce depression5. Aerobic activity in general is beneficial after brain injury. Churchill and colleagues demonstrates how aerobic exercise improved cerebral blood flow, oxygen extraction, and glucose utilization6. Lima explains how exercise results in activation of the sodium/potassium ATPase enzyme which is responsible for preserving appropriate levels of electrolytes within the cells7. In addition, Kim et al explained how exercise has been shown to inhibit the expression of BAX and Bcl-2 proteins which are a common byproduct of TBI that cause cell death8. Aerobic exercise such as walking should be performed for 30-40 minutes in order to achieve the recommended “moderate intensity” to make noticeable changes4.

When performing gait training in a rehabilitation setting, the evidence is clear that it should be task-specific in nature9,10,11. This proposes a challenge for the brain injury population because their motor impairments often prevent successful performance of everyday tasks such as ambulation. In the past, this limitation has led practitioners to perform therapeutic activities that mimic the stages of gait in order to develop the motor control and strength needed for upright walking9. However, the literature has suggested that perhaps inhibiting patients with brain injury from performing task-specific practice may place these individuals at a much higher risk for complications due to decreased mobility, development of contractures, and loss of potential for recovery during the window of greatest neuroplasticity9. For example, Matyas and colleagues demonstrated that adults post TBI were able to significantly increase their strength after completing a progressive resistance strength training program; however, there was no carry over into gait as illustrated by a lack of increase in maximal walking speed10. French demonstrated that repetitive functional task practice produced significantly more improved functional outcomes as compared to therapeutic exercise for lower extremities11. Hubbard gives guidance on the type of task practice that is most beneficial for this population. He states that the practice should be relevant to the patient’s goals and context, randomly assigned, repetitive and massed practiced, targeting whole task completion, and overlaid with positive feedback12. Hellweg and Zhu give evidence that shows the importance of increased intensity of practice5,13. For those patients who were given a greater intensity of gait training, their outcomes were significantly higher and time until discharge was reduced considerably as compared to the control groups who received one hour of physical therapy per day5,13. Elbert explains why specific task practice is beneficial. He completed a study using subjects who played string instruments and those who do not. For the individuals who played string instruments, imaging showed an expanded organization of the portion of the homunculus representing the fingers as compared to those who did not play a stringed instrument14. Hund-Georgiadis found that repeated task practice can create changes in the motor cortex in as little as thirty minutes15. Most rehabilitation programs require three hours of therapy per day; therefore, neuroplasticity should be occurring to great degrees in rehabilitation settings, reorganizing the motor cortex to regain functional ambulation if specific task practice is performed.

The current literature gives evidence of several types of task specific gait training techniques including conventional over-ground gait training with an assistive device, body weight supported treadmill training, aquatic therapy, rhythmic auditory stimulation, gait training using body weight supported robotic orthosis, virtual reality-delivered gait training, aerobic dance training, next step gait harness system, and neuroprosthesis with electric stimulation. This literature review will focus on the first five treatment strategies.

**Conventional Over-ground Gait Training**

Conventional over-ground gait training (COGT) is characterized by a patient ambulating over a regular floor surface with or without an assistive device as well as verbal and tactile cueing and assistance from the physical therapist16. This can also include separate exercises that are aimed at improving overall locomotor function16. This treatment was one of the only gait training techniques for many years until literature became more active in the development and research of other gait training options within the last 15 years. COGT is a good treatment option for patients with minimal motor deficits; however, there are many safety risks implied for both the patient and the therapist in the cases of more dependent patients16. Weakness, coordination deficits, ataxia, and postural instability are common impairments that prevent an individual from safely ambulating independently post TBI9,16. Because of this, they require support from a device or person. When the therapist’s hands are full providing upright support, initiating stepping, preventing lower extremity collapse, and encouraging weight shift; the therapist has less physical ability to provide motor learning principles to gait training such as cueing, correction, and feedback16. The therapist must also be extremely conscious of their body mechanics during gait training so as to avoid injury. Use of an assistive device can help to reduce the physical stress on the therapist; however, it often causes compensatory strategies such as forward lean16. A positive aspect of COGT is its direct translation to gait outcomes. Patients are not required to transfer ambulatory skills from a treadmill or water to the floor, but instead are practicing in the same context as their functional environment. In addition, practicing gait over ground allows for increased breadth of environments such as walking over and around obstacles, slopes, steps, high traffic environments, and uneven surfaces17. Brown completed a high level randomized controlled trial that found that partial body weight support devices for gait training are not superior to conventional over ground gait training for the TBI population16.

**Body Weight-Supported Treadmill Training**

Body weight-supported treadmill training (BWSTT) involves the use of a body weight-supported device that elevates the patient using a harness system while maintaining foot contact with the treadmill. Therapists assist the patient with weight shifting and stepping movements as needed. The theory behind gait rehabilitation through this technique is different from COGT. This approach was created as a result of research on spinalized cats that stated there is an inherent capacity within the spinal cord to perform a rhythmic locomotor pattern of the lower extremities without the assistance of upper motor pathways. This motor center is known as a ‘central pattern generator’ and can be refined and adapted through practice such as BWSTT18. Several studies have determined BWSTT to be a superior gait training technique to COGT for improving gait velocity and stride length in patients with similar neurological diagnoses such as stroke, Parkinson’s Disease, and Cerebral Palsy16,19,20. However, research into this topic for patients with brain injury is lacking in quality evidence. The general consensus from the literature is that BWSTT is equally as effective as COGT, but is not superior in regards to functional gait outcomes such as gait speed16. Wilson and Powell completed an RCT comparing the two gait training treatments for patients with TBI and found that all of the subjects demonstrated improvements in each of the following outcome measures: Functional Ambulation Category (FAC), Standing Balance Scale (SBS), Rivermead Mobility Index (RMI), and Functional Independence Measure (FIM). However, there was no statistical significance between groups for any of the measures19. Scores were higher for the COGT group on the FAC and scores were higher for the BWSTT group on the SBS, RMI, and FIM19. Wilson demonstrated that BWSTT may be more useful for patients with acute injuries as opposed to chronic injuries20. Freund showed through a case report that BWSTT may be beneficial in patients with TBI and cerebellar ataxia to significantly improve gait and balance as measured by the BBS, 10-MWT, and FAC21. Clark completed a study to determine best practices of gait training for use of a BWS device. He found that patients with TBI had decreased center of mass displacement and improved timing and stability when therapist assistance and upper extremity support were given22. Further research is required to make any definite conclusions about the effectiveness of BWSTT for the TBI population. Outside of gait related outcomes, BWSTT has multiple significant benefits such as decreasing the physical stress on the therapist, increasing safety for the patient, allowing specific task practice, and is both physiologically and psychologically beneficial for the patient and their families16.

**Rhythmic Auditory Stimulation**

Rhythmic auditory stimulation (RAS) is a specific type of music therapy that has been shown to be beneficial for the TBI population. It is used during treatment of motor deficits based on the evidence that shows that the sensory stimulus of auditory rhythm helps to improve motor control during rehabilitation23. Previous literature explains that music therapy is beneficial because the intrinsic rhythm found in songs acts as a source of feedback via auditory cueing for practicing movements that are intended to have a specific arrangement or organization23. Furthermore, there is evidence to show that auditory stimuli naturally activates the central nervous system in a way that excites muscle fibers into a state of preparation24. Muscle entrainment, the process of planning motion sequences and coordinating muscle movements to produce a smooth cycle, can be accomplished through RAS23. RAS was first found to be beneficial for improving timing and control of gait in patients with Parkinson’s Disease, stroke, and general aging25.

 Thaut completed a study that showed that after a gait training treatment of three weeks using RAS, patients post-stroke demonstrate a synchronization between auditory stimuli and motor responses that results in improved stride time, length symmetry, and weight bearing time on the paretic limb26. A similar study by Prassas and colleagues found reduced lateral displacement after gait training with RAS27. Thaut and McIntosh compared gait training with RAS to conventional gait training for patients about 15 days post stroke. Results showed that RAS gait training produced significantly better outcomes in gait velocity and stride length than the conventional gait training group28. There was also a significant difference in the reduction of variability of gastrocnemius firing during gait according to EMG studies. The timing of muscle activation was improved by 69% for the RAS group and only 33% for the conventional gait training group28. Similar results were found when comparing RAS gait training to NDT/Bobath based gait training29.

RAS gait training is also encouraged for the population of people with Parkinsons’s Disease. McIntosh et al demonstrated that RAS is highly beneficial in increasing velocity, cadence, and stride length in both patients who are currently taking medication to treat PD as well as those who are not taking medication30. The authors celebrate the observation that stride length was significantly improved as compared to the control group, which led to the increase in velocity. This is a large accomplishment considering short steps are the common presentation of patients with PD30. Another observation worth mentioning is the similar results found for both those on medication and those not medicated. This leads one to believe that RAS gait training may be beneficial for both those with and without basal ganglia dysfunction30. Based on the overwhelming amount of positive results for similar neurological cases, more studies would be beneficial if used to determine the effects of RAS on gait training for the TBI population.

**Robotic Automated Locomotor Training**

Robotic Automated Locomotor Training (RALT) is one of the newest techniques for therapeutic gait practice. It involves a robotic device that assists the lower extremities in performing the stepping motion while the patient is held upright through a harness system over a treadmill17. Some examples of robotic products currently on the market are Lokomat, Electromechanical Gait Trainer, and Lokohelp. After an extensive search of the literature, only one study was found that looked at the use of robotic assistance for patients after brain injury18. This was a case study that compared two subjects, age 22 and 26, one year and three years post injury, respectively after a 6 week treatment period of locomotor training with robotic assistance31. Results revealed a lack of statistically or clinically significant change in the outcome measures used (FAC, RMI, BBS, and MAS)31. According to their post treatment FAC scores, neither subject was ambulatory. In contrast, RALT has been shown to be beneficial in improving ambulatory independence in patients post stroke32. Additionally, Tefertiller et al explain that although the results were not statistically significant, there were evident clinical improvements in overground gait speed and endurance following locomotor training with robotic assistance for patients with incomplete spinal cord injury18. Other studies also noted the benefits of using RALT in a progression that begins with robotic assistance over a treadmill, then manual assistance over treadmill, and lastly manual assistance over ground18. This allows for gradual transition into a more realistic functional environment as the patient gains independence. In general, robotic assisted gait training was more beneficial for patients with acute neurological deficits as opposed to chronic18. RALT may be a valuable rehabilitation option for neurological patients because of its safety, ability to control the kinematics of the gait cycle, requirements for metabolic expenditure, and its task-specific qualities18. However, because the device provides such a controlled walking experience, the patient may lack the necessary error modifications and realistic sensory feedback that is available with conventional gait training. This may slow goal attainment when the patient is transferred to over ground training18. Though evidence is limited, it appears that patients of large size or considerable motor deficits may benefit from the safety of this controlled environment; while clinical judgment should be used for other neurologically involved patients18. Though results have been more promising for similar neurological disorders, the only evidence related to robotic gait orthoses for gait rehabilitation after brain injury states that there are no significant benefits to this treatment18. Sacco demonstrated that robotic-assisted gait training coupled with cognitive training through motor imagery was able to both improve functional gait and balance as well as extend the areas of activation in the primary motor area and the SMA of the brain as measured by fMRI17. These new findings demonstrate the importance of obtaining further research with improved study design in order to determine the effects of RALT for the brain injured population.

**Aquatic Gait Training**

Aquatic therapy is an excellent option for the TBI population because of the inherent benefits of the properties of water35,36,37. The buoyancy of water has the opposite effect as gravity, providing an upward force on an object that is submerged37. This has been shown to decrease one’s fear of falling35. This property can act as both an aid and a resistance tool during gait. Buoyancy significantly reduces weight bearing, therefore allowing patients with weakness to focus on the sequence and coordination of gait without fearing loss of balance37. It also provides a constant challenge to one’s core musculature, strengthening and improving stability. The hydrostatic pressure of water decreases pain and edema, allowing an increase in range of motion37. It also assists the heart by increasing venous return35. The viscosity of the water requires one’s muscles to work harder than they originally would on land in order to move through the resistance of the water, including the heart muscle which therefore increases cardiovascular fitness37. The resistance of the water requires the body to adapt to using both sides equally in order to maintain balance, improving muscle balance37. However, these same properties of water may pose safety risks for more involved patients. The buoyancy of water can reduce stability for both the patient and the therapists, making it difficult to provide assistance or hands-on correction37. This can be especially dangerous for a patient in the early stages of recovery with decreased attention and cognitive clarity. Conversely, aquatic walking has been shown to be beneficial for muscle reeducation in the TBI population because the resistance of the water provides an extended period of time for motor response to perturbations and loss of stability37. The resistance of the water allows for objects to naturally move slower, therefore prolonging the time for motor correction37. For these reasons, clinical judgment should be used when determining the suitability of aquatic walking for the patient at hand. Caution should be taken for patients with greater severity of injury or those recovering between Ranchos level five and eight. Aquatics is not appropriate for patients Ranchos level four and below36. Furthermore, severe spasticity may be a hindrance to one’s ability to balance in the water. Spastic, flexed limbs tend to sink while flaccid, weak muscles often float35. This may cause the individual to feel unbalanced an even roll toward the spastic side. Flotation devices are a helpful remedy to keep spastic extremities floating for improved balance during gait35. Also, warming the water to about 93 degrees is helpful in diminishing involuntary spastic movements37. Overall, studies show that aquatic therapy is psychologically beneficial in decreasing stress and anxiety, increasing concentration, and improving feelings of well-being and confidence35,37. It allows the patient to practice gait with minimal support and without the hindrance of assistive devices or equipment. The literature is void of research that focuses on aquatic therapy for patients after TBI; however, other studies have been successful in functional improvements with patients after stroke, acquired brain injury, and spinal cord injury. Significant improvements have been found when an aquatic gait program was established three times per week for eight weeks38. Patients with stroke improved their aerobic capacity, gait speed, strength of paretic limbs, and balance. Those recovering from SCI demonstrated increased endurance, strength, and functional abilities as well as a decrease in their severity of muscle tone and/or spasticity38. Those with acquired brain injury benefited from the aquatic walking by gaining improved ROM, balance, gait stability, strength, endurance, affect, self-esteem, and a decrease in ataxic movements38.

**Discussion**

The literature is beginning to develop with recommendations on determining the most appropriate outcome measures to use for gait reeducation in the TBI population. One must differentiate measures according to the patient’s level of independence with ambulation in order to better evaluate the available measures. For patients who are able to ambulate modified independent or independently, measures such as the 10-meter walk test (10MWT), the six-minute walk test (6MWT), gait speed, step length, and step width are the highest recommended for good psychometric properties and feasibility of use39. Walking speed, step length, and step width and the 6MWT both have excellent test-re-test reliability for patients with TBI (ICC values > 0.91 and 0.96, respectively)40. Von Loo and colleagues found that significant change in gait speed for this population is 0.15 m/s for comfortable walking, 0.25 m/s for fast-paced walking, 8 cm for step length, and 3 cm for step width41. For true improvement of walking capacity on the 6MWT, patients need to increase their distance by 45 meters which is equal to a gait speed increase of 0.10 ms-141. These authors suggest that if the patient is able, the 6MWT is a preferred tool over the 10m walk test because it includes the aspect of endurance and is a better predictor of community distance walking40,42. Walking speed measured via stop watch has excellent inter-rater reliability and concurrent validity of walking speed (ICC= 0.998 for both comfortable and fast speeds)41. These authors also proved that use of a stop watch is indicated for measurement of speed based on a perfect correlation between stop watch times and the gold standard, infrared timing gate measured times41. Unfortunately, when subjects are placed in a natural environment such as a hallway, parking lot, and shopping mall, the gait speed from original clinical tests was significantly different from the slower gait speeds measured in a functional environment (ICC values between -0.24 and 0.63)43. The clinical test with the greatest ecological validity was the comfortably paced 10MWT with an ICC of 0.63 when compared to an inpatient facility hallway43. The 6 MWT has high responsiveness and is a good predictor of cardiorespiratory fitness for patients in inpatient rehabilitation with brain injury44. The ability of the test to predict VO2 is increased when a measure of heart rate is included44. For the patient who is not able to ambulate independently, The Functional Independence Measure (FIM) and Barthel Index were both recommended by the TBI EDGE task force, meaning that they have good psychometric properties for the particular patient population and they are reasonable for use in the inpatient rehabilitation setting in regards to time and equipment use45. The FIM is an outcome measure that includes gait function as one of the many functional tasks measured46. It has very high precision, validity, and interrater reliability. As the patient begins to approach discharge, scores often max out, demonstrating its ceiling effects that occur in about 49-84% of patients in inpatient rehabilitation46. FIM is a great resource to gather a broad idea of a patient’s functional status, however is not sensitive to subtle changes in gait improvements46. The Barthel Index has low ceiling effects and is sensitive to change for those individuals who require assistance during gait45. Because many of these measures are not specifically for the purpose of measuring gait improvements in patients post TBI, Wilson and Swaboda completed a study on gait training for patients with TBI using numerous reliable outcome measures with the addition of a new measure for increased sensitivity to improvements in gait quality and progress20. The Missouri Assisted Gait (MAG) scale was created to bridge the gap of the lack of outcome measures that pick up on small motor ability changes during gait recovery. The MAG scale scores on patients separately on the right and left from 0-6 on the level of dependence during gait including the particular stages of the gait cycle with the problem area20. The MAG scale could be more beneficial as a tool for demonstrating patient improvement to an insurance company when other measures fail to illustrate gains, especially in the chronic brain injury population20.

The findings of this review served to outline the importance of gait training in individuals post brain injury, review the available treatment options for specific task practice, and choose the best outcome measures for evaluating significant change. Repetitive practice of task-centered activities such as walking instead of strength training is essential to making functional gains in ambulation5. For patients in the early stages of recovery after brain injury, some studies suggest that BWSTT or robotic assisted gait training may improve patient outcomes and decrease time in rehabilitation when compared to COGT16,17,31,33. However, these studies are few and lack sufficient psychometric properties to persuade change practice. The FIM and Barthel Index were shown to have the strongest psychometric properties for these individuals45. For patients in the later stages of recovery when gait is improved, RAS and aquatic therapy have both been shown to provide improved functional ambulation abilities such as gait velocity, balance, and control25,37. In general, patient presentation should direct the method of gait training that a therapist chooses. At this point, trial and error can help to narrow the path to which methods are most successful for each individual. The 6MWT and gait parameters such as step length, step width, and velocity are the best outcome measures for these patients39. These results provide encouraging preliminary evidence for choice in gait training; however, further research including randomized controlled trails with increased sample size and well matched controls would be beneficial for strengthening the evidence.

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