**PICO Question: In older adults with chronic gait deficits following a stroke, is using a biofeedback spilt-belt treadmill with error augmentation better than error minimization or traditional treadmill gait training to improve inter-limb symmetry during gait?**

**Introduction**

 Stroke is the leading cause of disability in the United States with 750,000 new incidences every year.5,7 At least half of the individuals who suffer a stroke live with residual deficits of hemiparesis in their limbs that affect daily function.7 Today, nearly four million people in the United States are living with chronic deficits from a stroke that limit their ability to function independently and participate in the community.11

 During the sub-acute phase of rehabilitation following a stroke, emphasis is placed on regaining basic functional mobility skills and performing activities of daily living.3 Although walking is a main focus during rehabilitation, current literature has great variability in the amount and type of intervention used for gait retraining.7 Researchers report that sixty to eighty percent of stroke patients are able to walk independently when they are discharged from rehabilitation, but the speed at which they walk is too slow to be functional and effective in the community.1 Because of this, many individuals who suffer from chronic deficits following a stroke will adopt a more sedentary lifestyle and develop a learned disuse of their affected limbs.5 This only propagates the situation and adds to the cost of chronic disability.

 Typical gait patterns of individuals following stroke are characterized by decreased walking speed, efficiency, and spatiotemporal symmetry.1,6 These individuals generally exhibit a decreased stance time on the paretic limb and increased stance time on the non-paretic limb. Energy costs for these individuals are also above normal due to the increased co-contraction during stance, loss of selective muscle control, and decreased propulsive forces that result in decreased step length of the paretic limb.6,8 It is these characteristic deficits that gain the attention of researchers to focus on reducing these deficits in order to assist their patients in regaining the ability to ambulate and function in the community.

 Traditional treadmill gait training has been well documented in research. However, the protocols found in literature for treadmill training vary greatly in frequency, duration, and magnitude.1,5,7-11 Treadmill gait training, as opposed to overground gait training, allows for high task repetition in a safe and controlled environment and investigators have reported improvements in walking speeds, cadence, aerobic capacity, perceived disability, and quality of life.5,7,11 However, this research does not seem to address differences in inter-limb symmetry, such as decreased stance time, step length, and propulsive forces of the paretic limb.8

 More recently, motor adaptation has taken the forefront on motor learning research and investigators have explored the concept of motor adaptation and applied it to treadmill gait training with individuals following a stroke. Motor adapation is the process of modifying or adjusting a movement from trial to trial on the basis of error feedback such that a new movement pattern is temporarily acquired to respond to new task demands.8 With new technology and equipment available, such as the LokoMat, virtual reality, and split-belt treadmill, researchers are now studying the effect of error minimization compared to error augmentation during treadmill gait training; and whether individuals following stroke are able to adapt, correct the errors, and maintain the new motor pattern created during training to improve inter-limb symmetry during treadmill and overground walking.8-10

 The purpose of this literature review is to outline the evidence found that supports treadmill training in patients with chronic deficits following a stroke and the improvements seen in these patients. Then, provide evidence for error augmentation during walking relearning tasks and whether that concept in motor learning can be transferred to chronic stroke patients to develop a more specific protocol to improve spatiotemporal gait asymmetries in individuals with chronic stroke deficits. The results of this literature review will provide evidence for clinicians to answer the question whether error augmentation, error minimization or traditional treadmill gait training is more beneficial for improving inter-limb symmetries in individuals with chronic stroke deficits.

**Evidence to support treadmill training for individuals in the chronic phase of stroke rehabilitation**

 The current literature involving treadmill gait training varies significantly in measurements, protocols, and outcomes. The following is a comparison of two studies that reported positive outcomes for treadmill gait training in individuals with chronic stroke deficits. The subject inclusion criteria, methods, and results will be compared for each study to attempt to determine a more universal protocol.

 In a long term treadmill gait training study, Patterson et al assessed the effect of treadmill training on spatial and temporal gait parameters. The study was a single group design of 42 subjects over the age of 40 who were more than six months post initial insult with residual hemiparetic gait. The intervention group walked on the treadmill at a moderate intensity and duration three times per week for six months. As the trial progressed, the intensity and duration of the treadmill training would increase as tolerated.7 The results of the intervention group were compared to a control group that received matched duration exposure to a therapist who performed stretching and 5 minutes of treadmill training at a low intensity. The treadmill training group demonstrated significant improvements in increased self-selected and fast walking speeds, economy of gait, peak VO2, stride length, cadence, paretic and non-paretic step length and time, symmetry in stance time between lower extremities, and percentage of double limb support time.7 Further, the investigators report that two-thirds of the improvement seen in velocity was a result of improved step length on both legs, as opposed to cadence.7 This study by Patterson provides specific information about gait parameters that need to be emphasized during training to see results.7 During gait retraining, clinicians need to emphasize an increase in step length for both limbs, as opposed to simply forcing a faster gait by increasing cadence.

 In a second study reviewed, Ada et al performed a double blind randomized, controlled trial that was much shorter in duration and incorporated overground gait training along with the treadmill training but provided similar results seen in the Patterson et al study.1,7 This study included participants who were between six months and five years post initial stroke and was conducted three times per week for only four weeks. The subjects in the treadmill training group walked for thirty minutes with an emphasis on increasing step length, with time split between treadmill training and overground training. Over the course of the study, the time spent on the treadmill was decreased.1 The treadmill training group was compared to a control group that performed a home exercise program of lower extremity stretching and strengthening, balance, and coordination exercises for the same duration. Ada et al reported a significant increase in walking speed, capacity, and step length but no difference in cadence or step width.1 This study reiterates the importance of emphasizing increased step length during training and task specific practice to see a more functional improvement in gait speed for individuals.

**The effect of error augmentation on motor learning during walking**

 Domingo et al performed a randomized, controlled trial to answer the question whether active assisted, error correction, or direct practice of a task improves performance the best.2 Neurologically intact college-aged students were randomly assigned to one of five groups and performed the task of walking on a balance beam for thirty minutes. Researchers reported on the number of errors during training and compared pre- and post-test performance. Two of the groups wore a destabilization device on their hips with different intensities of a destabilization force while walking on a standard size balance beam. One group walked on a narrow balance beam that was half the width of the standard beam. Another group simply practiced the task of walking on a standard balance beam. The last group wore an assistance device on their hips while walking on the standard beam.2 The pre- and post-tests were performed on the standard balance beam. Researchers reported that the group who practiced walking on the standard balance beam for thirty minutes showed the greatest improvement in pre- and post-test scores. The destabilization groups exhibited twice the number of errors during training compared to the standard group. While the assisted group required less assistance and showed improvement throughout the training session, no difference was noted between pre- and post-test scores. The group that walked on the narrow balance beam demonstrated a similar number of errors during training as the destabilization groups but showed a slightly greater improvement in performance.2 Investigators also reported an overall trend in the correlation between the movement of the sacral markers and the improvement in the number of errors between the pre and post test. The standard group demonstrated the greatest movement of the sacral markers while training and also showed the greatest improvement in pre- and post-test scores.2

 In a study involving individuals with chronic hemiparesis following stroke, Hornby et al evaluated the difference in gait improvements in therapist-assisted treadmill gait training versus robotic-assisted gait training.3 Forty-eight individuals with hemiparesis following a stroke more than six months prior and able to walk overground at least ten meters at a self-selected speed slower than 0.80 m/s without assistance were randomly assigned to either the therapist-assisted gait training group or the robotic-assisted treadmill gait training. Both groups underwent twelve training sessions for thirty minutes each. Body weight support was provided for those who needed it, starting at 40% support and decreasing in 10% increments each session as tolerated. The subjects began walking at 0.56 m/s during the initial session and increased to 0.83 m/s as tolerated and remained that speed for every subsequent session.3 Those in the therapist-assisted group had a single therapist provide manual assistance to advance the paretic limb as needed to maintain continuous walking. The robotic-assisted group was provided continuous symmetrical stepping assistance using the Lokomat. At the end of the training session period, the subjects in the therapist-assisted group demonstrated a significant increase in both self-selected and fast walking speeds overground compared to the robotic-assisted group. The therapist-assisted group also demonstrated a significant improvement in single limb stance time on the paretic limb at the subjects’ fast walking speed.3

Domingo et al and Hornby et al provide important information about motor learning and error augmentation versus minimization, as well as task specificity in practice.2,4 Domingo et al reports that the group that demonstrated the greatest improvements in pre- and post-test scores performed task specific practice, allowing errors and without assistance.2 The researchers conclude that error does need to occur for refinement of the task and to show improvement, but too much error can interrupt the learning of the task and a motor plan cannot be created or modified. This study also demonstrates that even though improvements may be seen during a training session when assistance is given, the improvement does not transfer when the assistance is no longer present.2 Hornby et al support the findings by Domingo et al involving assistance during training. The subjects in the therapist-assisted group that were forced to work harder during the training period demonstrated a significant increase in walking speeds and inter-limb symmetry. In contrast, the group who did not have to perform as much active effort during training, the robotic-assisted group, did not demonstrate any significant improvements following training despite assisted continuous symmetrical stepping during training.4 Overall, task specificity is important for motor learning, as is allowing the participant to make and correct his/her own errors.2,4

**Evidence to support split-belt treadmill training and its effect on walking adaptations**

 A new area of research that has recently gained attention is the use of a split-belt treadmill in gait training for individuals with neurologic deficits. In the following section, three different studies performed by Reisman et al using a split-belt treadmill will be compared for subject inclusion criteria, methods, and results.8-10

 The first study reported by Reisman et al is a quasi-experimental design that included a group of individuals with chronic stroke deficits and a group of age- and gender-matched healthy individuals.9 The protocol for walking on the treadmill consisted of three different periods, a baseline period, an adaptation period, and a post adaptation period. The baseline and post adaptation periods were six minutes each with the treadmill belts at the same speed. The adaptation period was fifteen minutes where one belt was moving at a speed of 1.0 m/s and the other belt was moving at a speed of 0.5 m/s. For the stroke subjects, two different sessions were performed to assess the difference in performance between each leg walking at the fast pace during the adaptation phase. The control group only performed one session. Reisman et al reported that overall, the group of stroke subjects performed similarly to the control group. This indicates that even with a cerebral insult, stroke patients are still able to adapt to a changing environment.9 The investigators also reported that for the six subjects who exhibited asymmetry during baseline, a statistically significant increase in symmetry was found in the post adaptation phase after they finished an adaptation phase where the paretic limb was on the fast belt (accentuating asymmetry during adaptation).9

 Reisman et al followed with a study that incorporated the treadmill training protocol with overground gait training.10 One major difference in protocol was that the fast walking speed was determined for each individual subject based on his or her fast walking speed overground. The slow walking speed was half of the fast walking speed. The subjects included two groups that consisted of eleven subjects who sustained a single stroke at least six months prior, and a group of age- and gender-matched healthy individuals.10 The subjects participated in one testing session that consisted of six different periods. The periods included an overground baseline period; a treadmill baseline period where both belts moved at the slow speed; an adaptation period for ten minutes where the treadmill belts were split with the leg with the shorter stance time set at the fast speed and the other belt set at the slow speed; a catch trial where both belts returned to the slow speed for 1 minute; another adaptation period for 5 minutes (for a total of 15 minutes of adaptation); an overground post-adaptation trial; and a washout period where the subjects walked on the treadmill for five minutes with both belts moving at the slow speed.10 Reisman et al reported that overall, the stroke group was able to adapt to the changes in the belt speeds during the adaptation phase and did exhibit some after-effects of a more symmetric gait during the washout period. The stroke group exhibited a statistically significant increase in symmetry and a greater transfer of the gait adaptation to overground walking than the control group.10

 The final study by Reisman et al involves a case study of a thirty six year old woman who suffered a hemorrhagic stroke one year and seven months prior.8 The woman participated in treadmill training for one hour sessions three times a week for four weeks. The investigators used the protocol from the adaptation phase of the previous study. The subject walked for five minute bouts on the treadmill with the adaptation period protocol and ended each session with five minutes of overground walking, with an emphasis on increasing step length of the paretic leg. The investigators reported an increased in self-selected and fast walking speeds, decrease in step length asymmetry from 21% to 7%, and improvement in score on the TUG and Fugl-Meyer lower extremity score. The investigators also performed a one month follow-up of outcome measures and reported that all of the measures remained consistent or improved from the original post-training score.8

 The studies by Reisman et al provide a protocol that may be used for treadmill training in individuals with chronic deficits following a stroke. By accentuating the gait asymmetry during treadmill training, the subject is able to adapt to the change and carry over some of the motor plan into the washout period on the treadmill and overground walking.8-10 However, there were some limitations to these studies. The first two studies were one time data collections and did not look at the long term effects of the treadmill training protocol. The third study did look at long term effects but it was only a case report of a young woman who suffered a stroke, which is not generalizable to the stroke population. More research needs to be performed to determine if the protocol used in the case study can benefit multiple individuals in the chronic phases of stroke rehabilitation.8

**Conclusions**

 Stroke is the leading cause of disability in the United States, and today, there are nearly four million people living with the chronic deficits from a stroke.7 Although sixty to eighty percent of stroke patients are able to walk when they are discharged from rehabilitation, the inter-limb asymmetry and slow speed is not functional for community ambulation.1 The benefits of treadmill training have been reported, including increased walking speed, capacity, and VO2.1,7 However, traditional treadmill gait training has not supported any improvement in inter-limb symmetry, which has been reported as the main culprit in decreased walking speed and economy of gait.1,7,8 With the new technology of split belt treadmills and the increased knowledge of motor learning, newer research has pointed to a protocol that has worked for a select number of individuals suffering from chronic stroke deficits. This literature review provides support that error augmentation during treadmill gait training, as opposed to error minimization or traditional treadmill gait training, leads to better improvements and transfer to overground walking.8-10 However, research is still indicated to provide a generalizable protocol for individuals with chronic stroke deficits that could be used more availably in the clinical setting.

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