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The Use of High Intensity Interval Training to Improve Gait in a Patient with Sub-Acute Stroke: A Case Report

Katherine Helmlinger
University of Iowa

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Katherine Helmlinger

DPT Class of 2018
Department of Physical Therapy & Rehabilitation Science
The University of Iowa

Abstract

Background: Residual hemiparesis is common after stroke and affects patients' ability to perform functional mobility and ambulation. Stroke patients often have decreased gait speed and endurance, limiting their ability to participate in the community. Treadmill training is one method that has been shown to improve gait outcomes after stroke. Preliminary evidence has suggested high intensity interval training (HIIT) can also improve gait outcomes in stroke patients, more efficiently and possibly to a greater degree. **Purpose:** The purpose of this case report is to 1) describe the use of HIIT as an intervention to improve gait in the sub-acute stroke population and 2) to present one patient's changes in functional outcomes after HIIT. **Case Description:** The patient was a 52-year-old male with ischemic middle cerebral artery stroke resulting in right-sided hemiparesis. The patient was admitted to a sub-acute rehabilitation facility in which he received 2 hours of physical therapy daily. **Intervention:** The patient participated in treadmill HIIT during physical therapy 3 times per week for 2 weeks (6 total sessions). The intensity was prescribed based on the maximal safe treadmill speed and the HIIT protocol consisted of a 60-second bout of activity followed by 60 seconds of rest. **Outcome Measures:** The 10-Meter Walk Test (10MWT) and 6-Minute Walk Test (6MWT) were used as primary outcome measures of this report. Timed Up and Go (TUG) and Berg Balance Scale (BBS) were used as secondary measures of function. **Discussion:** The patient was able to ambulate on the treadmill nearly 3 times faster than his self-selected walking speed overground. Gait speed and distance improved in this patient from pre- to post-intervention as well as functional independence with activities of daily living (ADLs) and ambulation. This case demonstrates the feasibility of incorporating HIIT, when appropriate, for patients in the sub-acute phase after stroke.

Keywords: Stroke; hemiparesis; hemiplegia; high intensity interval training; HIIT; gait training; neurology; physical therapy; rehabilitation

Background

Each year nearly 800,000 people experience a stroke in the United States, with approximately 87% being ischemic in nature[1]. Residual hemiparesis is common after stroke and can severely limit a patient's ability to perform basic mobility tasks and activities of daily living (ADLs). Ambulation, in particular, is often affected after stroke due to motor weakness. Many stroke survivors have lasting gait deficits, including impairments in gait speed, distance, step symmetry, postural stability, and ambulation efficiency[2]. Stroke rehabilitation often emphasizes improving gait mechanics and normalizing a patient's gait to achieve functional independence.

Common physical therapy interventions in stroke rehabilitation include task-specific training to target balance and functional mobility impairments. The use of a treadmill is one method of achieving task-specific walking practice after stroke. Treadmill training allows for repetitive stepping practice and can help facilitate a more normal gait pattern by forcing appropriate timing of steps between lower extremities[3]. A systematic review of the literature found that treadmill training, with or without body weight support, is effective in improving gait outcomes, including walking speed and endurance after stroke[4]. However, in most treadmill training studies, walking is performed continuously at a moderate intensity and there is less emphasis on the treadmill speed[4].

Recent evidence has suggested that high intensity activity during stroke recovery may be more effective at improving motor outcomes than moderate or low intensity practice[2]. One study in particular found that high intensity treadmill training resulted in greater improvements in gait outcomes compared to low intensity treadmill training of similar total stepping volume[5]. This suggests that the intensity of practice, in addition to specificity of training, is an important factor to consider in order to maximize locomotor recovery after stroke.

High intensity interval training (HIIT) is a strategy used to achieve high intensity bursts of concentrated effort followed by periods of rest, as opposed to continuous practice over a longer period of time[6]. This principle has long been used in healthy adults as a time-efficient alternative to achieve cardiovascular and muscular adaptations to exercise[6]. However, less evidence is available regarding the efficacy of this method in the stroke population. Several preliminary studies have demonstrated the effectiveness of HIIT to improve gait speed[7-9], distance[7, 10], and walking economy[7] in patients after stroke. One study, in particular, has compared HIIT with moderate intensity continuous training (MCT) in stroke patients. This study found significant improvements in gait outcomes in patients participating in HIIT, while those receiving MCT had no change from baseline[7]. This further supports the hypothesis that high intensity activity can result in even greater improvements in locomotor recovery after stroke.

Although there is emerging evidence in favor of HIIT in stroke rehabilitation, many variables remain unknown. The optimal dose for exercise prescription via HIIT has not been established, and available studies use different parameters for frequency and volume. The time of greatest effect is also unreported in current literature. Treadmill training within the first 3 months of stroke onset has been shown to have greater improvements in gait than if performed more than 6 months after stroke[4], suggesting the sub-acute phase may be ideal. However, to this author's knowledge, no study has compared the efficacy of HIIT based on time since stroke and, although limited, existing evidence suggests that HIIT can be effective in both the sub-acute (<6 months) and chronic (>6 months) phases post-stroke.

The primary purpose of this case report is to describe the use of high intensity interval training as an intervention option to improve gait in the sub-acute stroke population. The secondary purpose is to present changes in one patient's gait and functional mobility over a 2-week period of participating in high intensity interval training along with traditional rehabilitation interventions.

Case Description

The subject of this case report is a 52-year-old Caucasian male who initially presented to the emergency department with sudden onset of dysarthria and right-sided weakness. Upon further examination, he was found to have thrombi in the left internal carotid artery as well as in the M1 and M2 branches of the left middle cerebral artery (MCA). A Computed Tomography (CT) scan revealed a prominent region of infarction in the MCA territory with large ischemic penumbra. He received intravenous tissue plasminogen activator (tPA) and underwent successful thrombectomy on the day of admission. A repeat CT scan 4 days later showed evolving large left cerebral infarct with mass effect. Despite receiving tPA the patient had residual symptoms of right-side hemiparesis, global aphasia, and right homonymous hemianopia. The patient remained in acute care for 13 days before transferring to an inpatient rehabilitation facility for intensive physical, occupational, and speech therapies. He remained at this facility for 25 days and demonstrated improvements in functional mobility, though continued to require assistance at all times. He was then admitted to a sub-acute rehabilitation facility for further rehabilitation to gain independence with mobility prior to returning home. The patient's primary goal was to return to walking independently.

Clinical Impression I

At the time of admission to the sub-acute rehabilitation facility, the patient was not considered appropriate for HIIT due to his required level of assistance with ambulation and functional mobility tasks. He was unable to advance his right lower extremity independently, which would have limited his ability to perform treadmill training without physical assistance.

Examination I

The patient's initial examination was performed upon arrival at the sub-acute rehabilitation facility. Manual muscle testing was performed for bilateral upper and lower extremities with significant right-sided weakness noted. The patient's left side muscle strength was 5/5 for all major muscle groups tested. Sensory testing was not formally performed due to the patient's language impairments and inability to reliably provide information as to the degree of intact sensation.

Mobility and transfer tasks were also assessed during this evaluation, with the patient requiring minimum assistance (up to 25%) for rolling, supine to sit, and sit to stand transfers. He was able to maintain static sitting balance with supervision and required minimum assistance for blocking of the right knee to maintain static standing balance. To ambulate, the patient required moderate assistance (up to 50%) of 2 persons to block the right knee during stance phase, assist with advancing the right leg during swing phase, facilitate weight shift to the right, and prevent loss of balance. He utilized a right ankle-foot orthosis (AFO) and large base quad cane during ambulation.

Based on his required level of assistance, only the Berg Balance Scale was performed at the initial evaluation. The patient scored 15/56, which indicates a high risk for falls[11]. Due to required assistance with ambulation, standardized outcomes assessing gait were deferred at this time.

Clinical Impression II

Given the information obtained in the initial examination, the patient was not considered for HIIT. Due to the required level of assistance with ambulation, treadmill training would not have been feasible at this time. Following the initial examination, the patient received 5 weeks of traditional physical therapy that included emphasis on gait training and strength. At the start of week 3 the patient began participating in aquatic therapy interventions, incorporating gait in the pool for additional practice.

He made considerable progress in functional mobility over this time period and, after 5 weeks, was considered for HIIT as an adjunct to his current plan of care. During previous treatment sessions, he had successfully completed trials of slow speed treadmill training with as little as 10% body-weight support, requiring no physical assistance for lower extremity advancement.

A systematic review of literature has found that patients able to walk at the start of treadmill training benefitted most from the intervention, while those unable to walk did not benefit[4]. For this reason, HIIT was not considered until the patient was able to walk without additional physical assistance. Therefore, the primary measure to be re-evaluated to determine the appropriateness of implementing the HIIT protocol at this time was the ability to ambulate without physical assistance.

The patient was also relatively young and was extremely physically active before his stroke. He had no contraindications to aerobic exercise and it was believed he could benefit from and enjoy a high intensity training program, when appropriate.

Examination II

Five weeks after admission to the sub-acute rehabilitation facility, manual muscle testing was re-evaluated for the right upper and lower extremities. Although there were mild improvements, the patient continued to have notable right-sided weakness. Left side muscle strength remained within normal limits.

The patient was also re-assessed in a number of mobility and transfer tasks to determine functional improvement from the initial examination. The patient was able to perform rolling and supine to sit transfers with modified independence, requiring the use of a bed rail, but no physical assistance, to complete. Once sitting at the edge of the bed the patient was able to maintain static sitting balance independently and could tolerate mild perturbations without loss of balance. To perform a sit to stand transfer, the patient required contact guard assistance with occasional verbal cueing for foot positioning prior to standing. Once standing, the patient was able to maintain static standing balance with contact guard assistance and the use of a large base quad cane. It was noted that the patient had a mild left-sided lean with preferential weight bearing through the left lower extremity.

The patient was able to ambulate with contact guard assistance and the use of a large base quad cane and custom AFO on the right lower extremity. Occasionally the patient would require up to minimal assistance when he experienced a loss of balance. The patient utilized a step-to gait pattern with decreased stance time on the right lower extremity and had a significantly decreased gait speed. Due to limited functional endurance and required assistance with ambulation, the patient required a manual wheelchair for most mobility outside of physical therapy. He was independent in propulsion with the use of his left upper and lower extremities.

A number of standardized outcome measures were also evaluated at this time. These measures included the 10-Meter Walk Test (10MWT), 6 Minute Walk Test (6MWT), Timed Up and Go (TUG), and the Berg Balance Scale (BBS). The patient's ambulation speed was 0.30 m/s per the 10MWT and he was able to ambulate 476 feet without rest on the 6MWT. He was considered a high fall risk given his time to complete the TUG of 29.95 seconds and BBS score of 28/56[11, 12].

Clinical Impression III

The re-examination further supported the appropriateness for implementing the HIIT at this point in time, as the patient was able to ambulate safely overground without the physical assistance he had previously required. Although he had made substantial gains in mobility since admission, he still presented with significant impairments in gait. His gait speed was markedly decreased at only 0.30 m/s per the 10MWT and he had limited functional endurance measured by distance achieved via the 6MWT. Balance was also a concern, with the patient being categorized as a high fall risk based on scores from the TUG and BBS.

Given the patient's primary goal of improving independence with walking, as well as the significant deficits observed in walking speed and distance, the 10MWT and 6MWT were established to be the primary outcomes to quantify the patient's improvement post-intervention. Fall risk is also associated with independence with functional mobility and ambulation, hence the inclusion of the TUG and BBS as secondary outcome measures in this case report.

Intervention

The patient received up to 2 hours of physical therapy, 5 days per week at the sub-acute rehabilitation facility. The HIIT intervention took place during formal physical therapy sessions at a frequency of 3 days per week for a total of 2 weeks (6 sessions). A treadmill was selected as the mode to implement this intervention, as it provides repetitive, task-specific walking practice. Given the goal of improving ambulation, this was the mode that provided the most specificity to training.

Traditionally, the intensity of HIIT is prescribed as a percentage of heart rate reserve (HRR) or peak oxygen consumption (VO_2 max). However, the patient of this case report was unable to achieve a high enough aerobic intensity via treadmill training, due to motor impairments limiting maximum treadmill speed. In addition, the primary goal for this patient was to improve gait speed and distance, rather than aerobic capacity. For these reasons, treadmill speed was used to prescribe intensity instead, as it more closely aligned to the purpose of the intervention.

Before the training began, the patient was fitted with a harness secured to an overhead support system for safety and fall prevention. No body weight support was provided. The patient was allowed to wear his AFO and was permitted to use the treadmill handrail as needed throughout the training trials. The HIIT protocol involved 60-second bursts of treadmill walking at the maximum safe speed (described below), followed by a 60 second passive rest period in which the treadmill was stopped. Six high intensity intervals were completed, for a total HIIT time of 6 minutes.

The patient's maximum safe walking speed was determined prior to the start of each HIIT session. The desired speed was a minimum of 150% of the patient's self-selected walking speed as determined by the 10MWT. This value was chosen as it was used in a study evaluating HIIT in which target intensity was 150% self-selected overground walking speed[13]. Given the patient's self-selected walking speed of 0.30 m/s, the minimum desired treadmill speed to achieve 150% was 1.0 mph. Percentage of overground speed for each HIIT session is reported in Table 1.

Table 1: Treadmill Intensity Expressed as a Percentage of Baseline Gait Speed

HIIT Session	Fastest Safe Treadmill Speed	Percentage of Baseline Gait Speed (0.30 m/s)
1	1.1 mph	164%
2	1.5 mph	223%
3	1.7 mph	254%
4	1.8 mph	269%
5	1.9 mph	284%
6	2.0 mph	299%

A ramp test was performed to determine the maximum safe speed at the beginning of each HIIT session. This required the patient to walk on the treadmill as the speed was gradually increased. Each speed was held for a minimum of 20 seconds to evaluate for any gait deviations. Gait deviations were defined as a loss of balance, instances requiring physical assistance, or drifting backward on the treadmill belt. The maximum speed achieved without experiencing a gait deviation was used as the maximum safe treadmill walking speed. The first ramp test was performed starting at the slowest possible treadmill speed (0.5 mph). Each subsequent ramp test was performed starting at the maximum safe speed from the previous HIIT session. The treadmill speeds of the ramp tests are presented in Table 2.

Table 2: Treadmill Ramp Test

HIIT Session	Starting Ramp Speed	Maximum Safe Treadmill Speed
1	0.5 mph	1.1 mph
2	1.1 mph	1.5 mph
3	1.5 mph	1.7 mph
4	1.7 mph	1.8 mph
5	1.8 mph	1.9 mph
6	1.9 mph	2.0 mph

The patient trained at the established maximum treadmill speed for each interval in a given HIIT session. The treadmill incline remained at 0% throughout each trial. No physical assistance was provided, unless to prevent the patient from a loss of balance. Feedback was provided in a knowledge of results manner after each interval was completed, with minimal feedback provided during the high intensity bout.

As stated, the HIIT protocol involved 60 seconds of walking at the pre-determined maximum safe speed followed by 60 seconds of rest. The treadmill speed was increased to the target speed over a period of 25-45 seconds. Once at target speed, the patient maintained this pace for 60 seconds before stopping during the rest interval. This procedure continued for 6 repetitions, totaling 12 minutes of training. Figure 1 outlines the protocol used.

Immediately following the completion of the HIIT session, the patient participated in a short bout of overground walking. This is based on the principle that, while the treadmill forces an increase in gait speed and step length, overground walking is beneficial to reinforce the improved gait pattern achieved on the treadmill and may improve the translation to normal walking[14]. The remainder of the physical therapy session, as well as physical therapy sessions on alternate days, was spent working on additional interventions outlined in the patient's plan of care. As mentioned above, these included additional gait training (both land and aquatic based), balance challenges, strengthening exercises, neuromuscular electrical stimulation, and other functional activities.

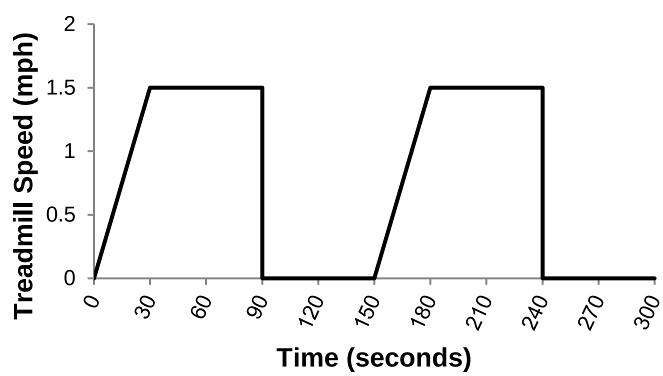

Figure 1: HIIT Protocol
Sample outline representing two intervals (performed in HIIT Session 2). Treadmill speed was ramped up to the maximum safe speed over 25-45 seconds. Treadmill speed was maintained for 60 seconds followed by rest where the treadmill was stopped for 60 seconds.

In addition to physical therapy, the patient received 30-60 minutes of both occupational and speech therapy 5 days per week. The sub-acute rehabilitation facility also had an extensive adaptive sports program for its residents. The patient participated in a variety of adapted sports on a bi-weekly basis for an additional 30-60 minutes per session. These activities included archery, kayaking, and fishing, and worked on incorporating balance and functional task training into the participation of activities the patient enjoyed prior to his stroke. After 8 weeks at the sub-acute rehabilitation facility, the patient was discharged home.

Outcomes

HIIT was included during the final 2 weeks of this patient's rehabilitation at the sub-acute rehabilitation facility. He made notable improvements in primary (10MWT and 6MWT) and secondary (TUG and BBS) outcome measures in the time just prior to HIIT implementation to discharge.

For the 10MWT the patient was instructed to walk at a self-selected walking speed over a distance of 10 meters with the middle 6 meters being timed. The test was repeated 3 times with the best of the 3 trials recorded. At baseline, prior to implementing the HIIT protocol, the patient's self-selected walking speed was 0.30 m/s. This speed placed this patient in the category of household ambulators (less than 0.4 m/s)[15]. Following the intervention, the patient's gait speed improved to 0.58 m/s, which re-categorized him as a limited community ambulator (0.4 m/s – 0.8 m/s)[15]. A substantial meaningful change in gait speed in patients with sub-acute stroke has been established as an improvement of at least 0.10 m/s[16]. The patient showed an improvement of 0.28 m/s, which surpasses this minimum, suggesting the increase in gait speed was meaningful. The 10MWT has excellent test-retest[17], interrater[18], and intrarater[17] reliability for stroke patients.

For the 6MWT the patient was instructed to walk as far as possible in 6 minutes. Prior to the HIIT intervention, the patient was able to ambulate 476 feet (145.1 meters). This distance improved to 631 feet (192.3 meters) post-intervention. The patient's improvement of 155 feet (47.2 meters) is greater than the 44 meters reported as a clinically meaningful improvement for stroke patients whose initial walking speed is slower than 0.40 m/s[19]. This test has excellent test-retest reliability for those who require an assistive device to walk[20]. It also has adequate interrater and intra-rater reliability[21].

To complete the TUG the patient was instructed to stand from a chair, walk a distance of 3 meters, turn around, walk back, and sit down in the chair. The patient was allowed one trial as practice and then the best of 3 trials was recorded. Initially the patient's time to complete the TUG was 29.95 seconds. Following the HIIT intervention, the patient was able to complete the TUG in 20.71 seconds. At this time, there is no established value for the minimal clinically important difference for the TUG in patients with stroke. However, the patient's change of 9.24 seconds does exceed the minimal detectable change of 2.9 seconds[22]. A TUG time of more than 14 seconds is associated with increased falls in stroke patients[12]. Although his time improved following the intervention, the patient's post-intervention time to complete still placed him at high fall risk. The TUG has excellent test-retest reliability[22], but no studies have reported the interrater or intra-rater reliability at this time.

The BBS includes 14 items scored on a 5-point scale of 0-4. The patient's total score prior to implementation of the HIIT protocol was 28/56. The patient's score improved to 39/56 at discharge. This improvement of 11 points is greater than the minimal detectable change of 8.1 points for stroke patients who ambulate with assistance[23]. A score of <45/56 on the BBS is associated with increased risk for falls[11]. Although the patient's score improved throughout his rehabilitation, he was still classified at a high risk for falls at discharge. The BBS has excellent test-retest reliability[24] as well as excellent interrater and intrarater reliability in sub-acute stroke patients[25].

Discussion

The use of HIIT in the stroke population has gained popularity in recent years, with preliminary data suggesting it is effective for improving mobility after stroke. However, there are several barriers to the implementation of HIIT in the stroke population, including cardiovascular deconditioning as a result of acute hospitalization as well as motor and balance impairments resulting from the stroke. The traditional method of prescribing intensity based on HRR or VO_2max may be ineffective or impractical in patients post-stroke. Rather, neuromuscular intensity may be more beneficial as a measure of prescribing intensity in the stroke population. Several studies investigating HIIT after stroke have utilized maximum walking speed rather than heart rate to determine training intensity[7-9, 26, 27], as is used in this case report. This patient, in particular, was able to ambulate at 299% of his self-selected overground walking speed during the final treadmill HIIT session, well exceeding the target intensity of 150%.

HIIT via a treadmill allows for repetitive walking practice at a higher intensity than what can be achieved overground in the same amount of time. This time-efficient method allows for additional physical therapy interventions to be performed within a single 60-minute physical therapy session. Additionally, the rest periods allow for opportunities to provide the patient feedback, which could be used to enhance motor learning.

The mechanism underlying the effectiveness of HIIT remains unclear. One potential mechanism to explain the improved motor abilities following HIIT intervention is changes in neuroplasticity. Intensity is a critical variable to consider with the prescription of exercise, but it is also important for modulating neuroplasticity in healthy individuals[28]. Higher intensity exercise has been suggested to increase the expression of brain-derived neurotrophic factor (BDNF) and insulin-like growth factor I (IGF-I), which can influence the motor recovery after neurologic insult[29]. HIIT in particular has been shown to improve BDNF and may account, at least in part, for improvements in motor function and functional abilities[29].

The patient of interest in this case report showed improvements in a number of standardized outcome measures, as well as functional mobility tasks, over the course of his rehabilitation. Although his total length of stay was 8 weeks, HIIT was only included in the final 2 weeks. In this time the patient's improvement consistently exceeded the minimal clinically important difference (MCID) for selected outcome measures. The patient was also able to achieve his goal of independent ambulation prior to returning home at discharge.

Although substantial improvements are presented in this case report, it is not possible to directly measure the effect of the HIIT intervention on this patient's functional improvements. Due to the multidimensional approach to this patient's rehabilitation, there were multiple variables that likely impacted the patient's functional recovery. These variables include the complementary physical therapy interventions as well as time and natural progression of recovery. Although no conclusions can be made as to the efficacy of HIIT in this report, it should be noted that the patient did not experience any adverse events and functional mobility in multiple domains improved. The patient was also able to achieve his goal of ambulating independently at discharge. This report suggests that HIIT is a feasible intervention option for patients with gait impairments in the sub-acute phase after stroke.

The available research on HIIT in stroke patients is still in its beginning stages. Continued research and discussion is required to further evaluate the optimal training parameters, the ideal timing post-stroke to implement the training, and HIIT's specific impact on motor learning. Additional investigations could also explore the use of high intensity training for motor recovery in other neurological conditions. Although there is still a great deal to be discovered, this case report highlights one example of how HIIT can be successfully implemented in the sub-acute rehabilitation of a patient following stroke.

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