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# Feasibility of single session high-intensity interval training utilizing speed and active recovery to push beyond standard practice post-stroke

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## Abstract

**Background—**Improvement in overground walking speed reduces dependency and is a central focus in post-stroke rehabilitation. Previous studies have shown that high-intensity interval training (HIT) can significantly improve functional and health-related outcomes in neurologically health individuals more so than traditional approaches. Emerging evidence suggests the same may be true post-stroke.

**Objective—**The purpose of this study was to assess the feasibility of a single session, novel HIT design.

**Methods—**Participants walked on a treadmill, alternating between one minute at high-intensity and one minute at low-intensity for 20 minutes, adjusting the speed of the treadmill to dictate intensity. Treadmill speeds were determined from overground self-selected walking speed (SSWS).

**Results—**No adverse events occurred during the training sessions. High-intensity treadmill speeds were significantly faster than treadmill SSWS (standard practice; +227%; $p < 0.0001$) and overground SSWS (+142%; $p = 0.003$). 15 of the 21 subjects were able to walk on the treadmill at 150% of overground SSWS; with the remaining individuals ($n = 6$) walking at 123% of overground SSWS. Average peak heart rate during HIT was 90% of age-predicted max.

**Conclusions—**These results demonstrate the feasibility of this single session HIT design and suggest that individuals following stroke are capable of prolonged training at speeds significantly faster than standard practice. Additionally, this training intensity elicited heart rate responses in the upper range of vigorous exercise. Future studies are needed to investigate a progressive HIT intervention applying this design and its effects on functional outcomes as well as cardiovascular fitness.

Disclosure statement
The authors report no conflicts of interest.

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**Keywords**

Chronic stroke; exercise; high-intensity interval training; walking speed

## Introduction

Improving gait and gait-related activities, specifically walking speed, is the most often stated goal during rehabilitation post-stroke; however, it is not clear how best to maximize walking outcomes.[1] Previous work in the fields of motor control and exercise physiology suggest the intensity of task-specific practice strongly influences neuromuscular and cardiopulmonary factors underlying locomotor function.[2] High-intensity interval training (HIT) is an approach that utilizes short bursts of high-intensity exercise with interposed low-intensity (recovery) periods.[3] The typical approach to HIT has been to prescribe intensity based on a percentage of max heart rate (HR), heart rate reserve or oxygen consumption; meaning intensity is set based on cardiopulmonary responses to exercise.[4–6] Limited research has examined the use of a performance-based outcome (e.g. treadmill speed) to set interval design.[7,8] These two studies have limited their high-intensity portion of the interval to only 30 seconds of walking at max treadmill speed with varying lengths of stationary recovery. To date, concern about whether individuals following stroke can feasibly achieve the intensities administered during HIT has limited implementation into clinical settings as there are concerns for orthopedic safety due to severe motor impairment and cardiovascular safety.[3] As such, the purpose of this brief report was to assess the feasibility of a novel HIT design in individuals with chronic post-stroke hemiparesis. It was hypothesized that HIT would be feasible within the chronic stroke population as well as training speeds being significantly faster than standard practice and overground self-selected walking speed (SSWS).

## Materials and methods

Twenty-three individuals performed a single session of HIT. All data were collected at the Medical University of South Carolina Stroke Recovery Research Center in the Motor Performance Laboratory. Subjects were recruited and training data were collected during February to June of 2017. Inclusion criteria were: (1) age 18–85; (2) at least 6 months post-stroke; (3) residual hemiparesis in the lower extremity (Fugl-Meyer LE, motor score < 34); (4) provision of informed consent. Exclusion criteria were: (1) intermittent claudication while walking < 200 meters; (2) history of congestive heart failure, unstable cardiac arrhythmias, angina or dyspnea at rest or during activities of daily living; (3) severe arthritis or other problems that limit passive range of motion; (4) history of deep vein thromboses or pulmonary embolism within six months; (5) uncontrolled diabetes or frequent insulin reactions; and (6) severe hypertension with systolic > 200 mmHg and diastolic > 110 mmHg at rest. All procedures were approved by the Institutional Review Board at the Medical University of South Carolina.

Prior to HIT, overground SSWS was measured on a 20-ft. long gait mat (GAITRite, CIR Systems Inc.; Sparta, New Jersey). The average of two trials was used to calculate treadmill training speed. HIT was 20 minutes of treadmill walking (Woodway, Woodway USA, Inc.;

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Waukesha, WI), which included alternating between one minute of lower intensity walking with one minute of higher walking (1:1 ratio). During warm-up and cool down, individuals walked at a comfortable pace for 3–5 minutes. Treadmill incline was 0 degrees during training sessions. The goal for each individual was to walk at 150% of overground SSWS for high-intensity and 50% of overground SSWS for low-intensity parts of the interval. For example, if an individual walked at an overground SSWS of 0.80 m/sec then low-intensity walking was performed at 0.40 m/sec and high-intensity walking at 1.20 m/sec (Figure 1A). If individuals could not walk at 150% of overground SSWS then the fastest speed that the individual could walk was determined and used for high-intensity walking speed. The low-intensity speed was then adjusted to the same percentage below overground SSWS as the high-intensity percentage above overground SSWS. For example, if the highest treadmill speed achieved was 135% of overground SSWS then the low-intensity treadmill speed was set to 65% of overground SSWS (Figure 1B). 150% was selected as the high-intensity goal because approximately 30% of participants at our center were able to modulate speed over ground in the range of 140–160%,with 50% of individuals falling below 140% and 20% of individuals above 160%. Therefore, we felt the 150% criteria could be achievable but challenging. For the low-intensity part of HIT, 50% was used as the criteria because it would be a speed that gave the individuals recovery but was still active exercise. To compare training speeds to current practice, prior to training individuals walked on the treadmill at a speed that they felt was similar to their overground SSWS.

To determine age predicted HR max two equations were used: (1) 208 – (0.7 × age), for the individuals not on beta blockers, and () 164 – (0.7 × age), for the individuals on beta blockers.[9,10] HR and blood pressure (BP) were monitored prior to, during, and for 15 minutes following completion of each training session. Sessions were terminated if the subject requested to stop, excessive BP increases for systolic > 200 mmHg or diastolic > 110 mmHg, a drop in systolic BP > 10 mmHg, or inappropriate bradycardia (drop in HR > 15 bpm). Participants wore a harness mounted to the ceiling to ensure safety in the case of loss of balance.

All comparisons were made utilizing independent t-test's with an a priori level of significance set at $\alpha = 0.05$. This manuscript conforms to the STROBE Guidelines.

## Results

Of the 23 participants, 21 were able to walk on the treadmill at speeds faster than overground SSWS (Table 1); two individuals were not able to reach overground SSWS on the treadmill and therefore not included in final data analyses. Participant characteristics ranged widely in age (22–81 years), time since stroke (8–152 months), lower extremity motor function (13–33 score; FMA-LE, Fugl-Meyer Assessment Lower Extremity), and overground walking speed (0.25–1.17 m/s).

None of the participants stopped training early. None of the participants had unexplained changes in HR or BP during training or during 15-minute post-training assessments. Additionally, none of the participants experienced any falls that required training to be stopped or the safety harness to be activated. On average, participants trained at an average

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speed 142% of overground SSWS ($p = 0.0003$) and 227% of treadmill SSWS $P < 0.0001$) during the high-intensity portion of HIT, respectively (Table 2). Average treadmill SSWS (0.49 ± 0.20 m/s) was similar to the low-intensity interval treadmill speed (0.45 ± 0.23 m/s). HR during the training sessions showed that the average peak HR was 90% of age-predicted HR max; placing cardiorespiratory intensity at the higher end of the vigorous intensity range (64–90%).[11]

Fifteen individuals were able to meet a priori HIT treadmill training speed criteria of 150% overground SSWS. Overground SSWS for this sample was 0.68 ± 0.29 m/s (0.25–1.17 m/s). Thus, the high-intensity average treadmill speed prescribed was 1.03 ± 0.43 m/s (0.38–1.76 m/s) and the low-intensity average treadmill speed was 0.34 ± 0.14 m/s (0.13–0.59 m/s). Of note, the individuals that were not able to achieve 150% of overground SSWS ($n = 6$) had an average overground SSWS of 0.93 ± 0.22 m/s (0.59–1.15 m/s), thus their high-intensity treadmill speed average was 1.15 ± 0.29 m/s (0.69–1.49 m/s) and the low-intensity treadmill speed average was 0.72 ± 0.18 m/s (0.49–0.90 m/s); equating to ±23% of overground SSWS. There was a significant difference between overground SSWS for individuals that met the 150% and 50% criteria and individuals that did not meet criteria ($p = 0.04$).

## Discussion

These results suggest that this novel HIT design, which utilizes overground SSWS to set training speed, an active recovery period, and an intensive 1:1 interval ratio is acutely safe and feasible in individuals with chronic post-stroke hemiparesis. These individuals were able to walk on a treadmill at speeds approximately double typically utilized during standard treatment approaches (i.e. treadmill SSWS) and significantly faster than their overground SSWS. These results suggest that current practice standards or even walking slightly faster than current practice standards significantly underestimate walking speed ability post-stroke.

As a group, our sample would be considered limited community ambulators (SSWS = 0.75 ± 0.29 m/s); however, individual speeds ranged from home ambulators (<0.40 m/s; $n = 3$) to limited community ambulators (0.40–0.80 m/s; $n = 9$) to full community ambulators (0.80–1.32 m/s; $n = 9$).[12,13] Of the 21 participants, 14 individuals trained at speeds that would place them into the next highest walking speed category. Two of the three home ambulators trained at limited community ambulator speeds, six of the nine community ambulators trained at community ambulatory speeds, and six of the nine community ambulators trained at speeds that would allow them to cross a street safely.[13]

In this study, walking speed, as opposed to aerobic capacity, was used as the variable upon which intensity was prescribed because the primary goal in future studies is to improve walking speed. Walking speed is a valid, reliable, and sensitive measure commonly used to assess functional capacity, general health status, mobility disability, and response to therapy.[13] Significant improvements in walking speed are associated with reduced dependency, functional impairment, walking disability as well as risk of death, hospitalizations, and falls.[13]

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Importantly, walking speed is easily measured in both research and clinical settings, thus allowing for easy translation of findings between settings, which is not as easily accomplished for measures such as aerobic capacity.

Strenuous exercise is the most accessible, effective, pluripotent, and safe intervention to improve and maintain health.[14] Our single session training prescription, as well as previous literature with differing training paradigms, have shown no adverse events during or immediately after training sessions as a result of this type of intensive exercise.[4,8,15,16] The benefits of this training style go beyond physiological changes, as it has been reported that HIT is more enjoyable, mentally engaging, and time efficient, as well as potentially the most important factor, a noticed improvement in adherence to training.[8,17] However, there is still much to learn about responses, both physiological and behavioral, to higher intensity (specifically HIT) training in individuals with chronic stroke.

A major limitation to this study was that feasibility of HIT was only assessed during training (e.g. participants stopping training, adverse HR or BP responses, mechanical faults) as well as 15-minute post-training. Therefore, it is not known how participants felt hours to days following training when delayed onset muscle soreness typically occurs. Thus, we do not know if there are effects of this type of training that may impact longitudinal investigation. Additionally, only one session was completed by the individuals and it is not known how individuals would response to multiple sessions at this study's set intensity. That said, future directions include assessing long term feasibility and adverse events as well as changes in walking speed and aerobic capacity over an intervention period utilizing this HIT training design. It should be noted here that individuals with faster overground walking speeds will need to be considered differently than slower individuals during intervention training designs. During our study individuals that met the 150% criteria walked significantly slower overground than individuals that did not meet the training goal. Therefore, to ensure appropriate intensity in reached and maintained over progressive training interventions other training factors will need to be adjusted (e.g. treadmill grade) as max treadmill speed may be reached fairly quickly. Questions also remain about response to training interventions as well as how the magnitude of improvements resulting from interval training differ from other training styles (e.g. cycling), especially when matched for total work. Importantly, this training design elicited an average peak HR response at the high end of vigorous exercise range, suggesting that future studies should include assessments of aerobic capacity. The translation of spatial-temporal, kinematic, and kinetic changes to gait that occur during HIT to overground SSWS changes is still unknown.

## Acknowledgments

Funding

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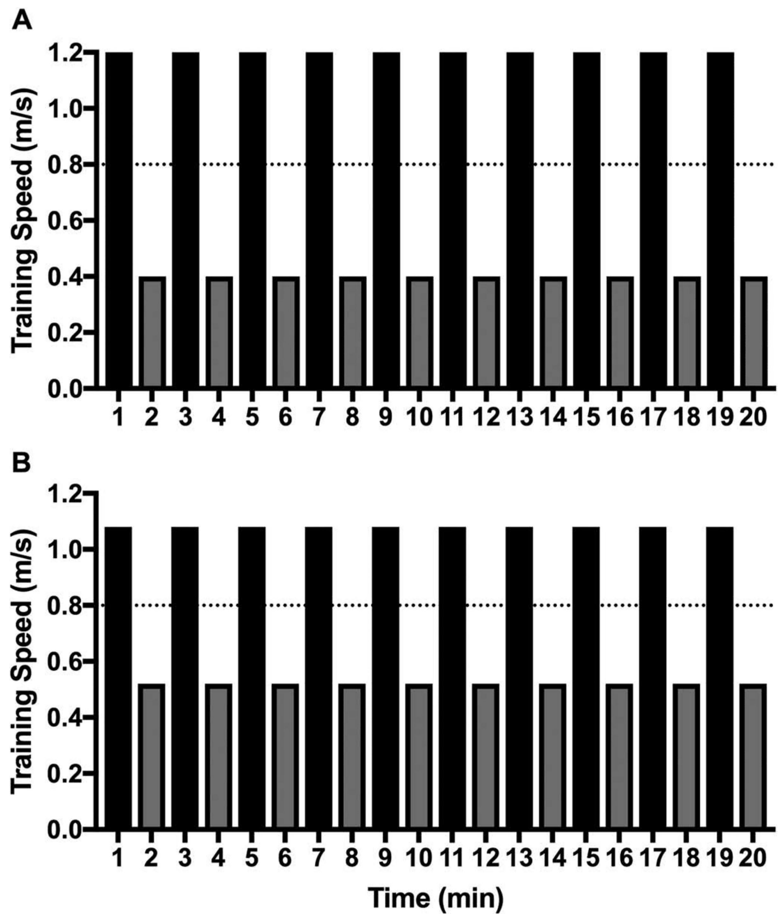


**Figure 1.**

Example of a training design for individuals that met 150% and 50% training criteria (a) and how training criteria was adjusted for individuals that were not able to meet the 150% and 50% training criteria (b). In these examples, the individual's overground self-selected walking speed was 0.80 m/s (dotted line).



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**Table 1.**

Participant characteristics.

| | ***n* = 21** |
|---|---|
| Age[a] | 56.48 ± 15.1 (22–81) |
| Sex (M/F) | 10/11 |
| Stroke Type (I/H)[b] | 15/6 |
| Hemiparetic Side (L/R)[c] | 6/15 |
| Time Since Stroke[d] | 53.86 ± 45.6 (8–152) |
| FMA-LE[e] | 23.87 ± 5.0 (13–33) |

Continuous variables (Age, Time Since Stroke, FMA-LE): mean ± standard deviation; (): range from lowest to highest.

Categorical variables (Sex, Stroke Type, Hemiparetic Side): frequency counts.

[a] Years.

[b] I: Ischemic; H: Hemorrhagic.

[c] L: Left; R: Right.

[d] Months.

[e] Fugl-Meyer Assessment-Lower Extremity: total score for lower extremity motor portion.

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**Table 2.**

Treadmill and self-selected walking speeds.

| | HIT Treadmill Speeds | | SSWS | |
|---|---|---|---|---|
| | **Low Intensity** | **High Intensity** | **Overground** | **Treadmill** |
| Walking Speed[a] | 0.45 ± 0.23 | 1.06 ± 0.39 *† | 0.75 ± 0.29 | 0.49 ± 0.20 |
| Range[b] | 0.13–0.90 | 0.38–1.76 | 0.25–1.17 | 0.20–0.90 |

HIT: High-Intensity Interval Training.

SSWS: Self-selected walking speed.

[a] m/sec ± standard deviation.

[b] m/s from lowest to highest.

* Significant difference between high-intensity treadmill speed and overground SSWS.

† Significant difference between high-intensity treadmill speed and treadmill SSWS.

OBE statement—checklist of items that should be included in reports of observational studies.

| | Item No. | Recommendation | Page No. | Relevant text from manuscript |
|---|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 | Line 1 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 1 | Lines 4–22 |
| **Introduction** | | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 2 | Lines 26–39 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 2 | Lines 39–43 |
| **Methods** | | | | |
| Study design | 4 | Present key elements of study design early in the paper | 2–3 | Line 46; Lines 58–79 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 2 | Lines 46–49 |
| Participants | 6 | (*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up | 3 | Lines 49–57 |
| | | *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls | | |
| | | *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants | | |
| | | (*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed | N/A | N/A |
| | | *Case-control study*—For matched studies, give matching criteria and the number of controls per case | | |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 3–4 | Lines 58–86; Figure 1 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 3–4 | Lines 58–86 |
| Bias | 9 | Describe any efforts to address potential sources of bias | N/A | N/A |
| Study size | 10 | Explain how the study size was arrived at | N/A | N/A |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | N/A | N/A |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 4 | Lines 87–88 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | N/A | N/A |
| | | (*c*) Explain how missing data were addressed | N/A | No missing data. |
| | | (*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed | N/A | N/A |
| | | *Case-control study*—If applicable, explain how matching of cases and controls was addressed | | |
| | | *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy | | |
| | | (*e*) Describe any sensitivity analyses | N/A | N/A |



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| | Item No. | Recommendation | Page No. | Relevant text from manuscript |
|---|---|---|---|---|
| **Results** | | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—e.g. numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed | 2/4 | Line 46; Lines 91–93 |
| | | (b) Give reasons for non-participation at each stage | 4 | Lines 92–93 |
| | | (c) Consider use of a flow diagram | N/A | N/A |
| Descriptive data | 14* | (a) Give characteristics of study participants (e.g. demographic, clinical, social) and information on exposures and potential confounders | 4–5 | Lines 93–99; Figure 1 |
| | | (b) Indicate number of participants with missing data for each variable of interest | N/A | No missing data. |
| | | (c) *Cohort study*—Summarize follow-up time (e.g. average and total amount) | N/A | N/A |
| Outcome data | 15* | *Cohort study*—Report numbers of outcome events or summary measures over time | N/A | N/A |
| | | *Case-control study*—Report numbers in each exposure category, or summary measures of exposure | N/A | N/A |
| | | *Cross-sectional study*—Report numbers of outcome events or summary measures | 5 | Lines 99–114 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g. 95% confidence interval). Make clear which confounders were adjusted for and why they were included | N/A | N/A |
| | | (*b*) Report category boundaries when continuous variables were categorized | 5 | Lines 99–114; Table 2 |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | N/A | N/A |
| **Discussion** | | | | |
| Key results | 18 | Summarize key results with reference to study objectives | 6 | Lines 117–123 |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | 7 | Lines 150–170 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 6–7 | Lines 124–149 |
| Generalizability | 21 | Discuss the generalizability (external validity) of the study results | 6 | Lines 132–137 |
| **Other information** | | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 8 | Lines 175–176 |

[a]Give information separately for cases and controls in case–control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.