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Effectiveness of High-Intensity Interval Training for Fitness and Mobility Post Stroke: A Systematic Review.

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Title

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Abstract

Objective: To evaluate the evidence on the effectiveness of high-intensity interval training (HIIT) in improving fitness and mobility post stroke.

Type: Systematic review.

Literature Survey: Medline, Embase, CINAHL, PsycINFO, and Scopus were searched for articles published in English up to January 2018.

Methodology: Studies were included if the sample was adult human participants with stroke, the sample size was ≥3, and participants received >1 session of HIIT. Study and subject characteristics, treatment protocols, and results were extracted.*Synthesis:* Six studies with a total of 140 participants met inclusion criteria: three randomized controlled trials and three pre-post studies. HIIT protocols ranged 20 to 30 minutes per session, 2 to 5 times per week, and 2 to 8 weeks in total. HIIT was delivered on a treadmill in five studies and a stationary bicycle in one study. Regarding fitness measures, HIIT produced significant improvements in peak oxygen consumption compared to baseline, but the effect was not significant compared to moderate intensity continuous exercise (MICE). Regarding mobility measures, HIIT produced significant improvements on the 10-Meter Walk Test (10MWT), 6-Minute Walk Test (6MWT), Berg Balance Scale (BBS), Functional Ambulation Categories (FAC), Timed Up and Go Test, and Rivermead Motor Assessment compared to baseline. The effect of HIIT was significant compared to MICE on the 10MWT and FAC, but not on the 6MWT or BBS. *Conclusions:* There

is preliminary evidence that HIIT may be an effective rehabilitation intervention for improving some aspects of cardiorespiratory fitness and mobility post stroke.

Evidence: Level I

Introduction

Stroke is one of the leading causes of death and disability among adults.[1] Individuals often have significant deficits in coordination, balance, gait, and gross motor function following stroke, which impact their ability to perform activities of daily living.[2] Rehabilitation of stroke impairments and concomitant disability is of vital importance to improving function, and thus enhancing quality of life. However, individuals with stroke have approximately twice the energy costs for locomotion[3] and half the cardiorespiratory fitness[4] when compared to healthy individuals, contributing to considerable inactivity and deconditioning.[5] Deconditioning after stroke is a major barrier to full participation in stroke rehabilitation programs, which attenuates potential motor recovery.[6] Moreover, maintenance of cardiovascular fitness is essential in reducing the risk of recurrent stroke.[7]

Given the barriers to rehabilitation and increased risk of stroke recurrence, there is a growing initiative to improve cardiorespiratory fitness in individuals post stroke.[8] Several studies have demonstrated improvements in aerobic capacity and gait with three to six months of moderate-intensity continuous exercise (MICE).[9-11] Additional benefits of MICE include increased power,[12] reduced spasticity,[12] and improved cognitive function.[13] As well, numerous studies have shown that brief repeated sessions of high-intensity training lead to skeletal muscle changes in energy metabolism that resemble traditional endurance training in healthy individuals.[14-16] Currently, optimal cardiorespiratory training parameters in stroke rehabilitation remain unknown.[17]

A training protocol commonly referred to as high-intensity interval training (HIIT) consists of intermittent bursts of effort separated by periods of recovery.[18] Among healthy individuals, HIIT has demonstrated greater effectiveness in improving aerobic capacity[19-21] and superiority in time efficiency[18] when compared to MICE. A key mechanism of HIIT appears to be increased neuromuscular recruitment,[18] resulting in increased efficiency of both skeletal[22-25] and cardiac muscle.[26-28] This mechanism is highly relevant in stroke, as neuromuscular recruitment deficiency is a primary stroke impairment.[29] Due to underlying medical comorbidities and functional limitations of individuals post stroke, task performance safety in terms of physical and physiological events may be a concern during HIIT. However, it has been shown that HIIT is a safe and effective intervention in a variety of clinical populations, including those with cardiovascular and respiratory diseases.[30-32]

Stroke rehabilitation guidelines recommend MICE to improve cardiorespiratory fitness;[33] however, the intensity is often not sufficient to observe substantive improvement.[34] As a result, MICE is not routinely implemented in clinical practice.[33] Research has consistently demonstrated that higher intensities of stroke rehabilitation yield improved functional outcomes, when controlling for frequency and duration.[35-37] As a high-intensity and time-efficient intervention, HIIT may provide an alternative to MICE that is more feasible to implement and results in more pronounced benefits. A general review by Boyne et al.[38] provided an overview of the basis for HIIT post stroke, including safety, feasibility, and efficacy. However, a formal systematic review is essential to providing a more thorough and updated summary of HIIT as it applies to stroke rehabilitation. Therefore the objective of the current review is to determine the effectiveness of HIIT in improving cardiorespiratory fitness and mobility following stroke.

Methods

The current review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[39]

Search Strategy

A systematic literature search for articles published up to January 2018 was conducted using the following electronic databases: Medline, Embase, CINAHL, PsycINFO, and Scopus. Filters were applied in each database to restrict searches to articles published in English. Combinations of the following terms were used: stroke, high intensity interval training, high intensity intermittent exercise, and speed dependent treadmill training. Variations of subject headings and keywords were tailored to each database. Full search strategies for each database are reported in the Appendix. References of included studies were scanned to ensure no relevant articles were missed in the searches.

Study Selection

Studies were included in the current review if they met the following three *a priori* criteria:

1. the entire study population was adult human participants with stroke;
2. the sample had three or more participants;
3. the participants received more than one session of HIIT.

After removal of duplicates, studies were screened for eligibility based on title and abstract. Full-text articles were retrieved for the remaining studies and further screened for eligibility. Studies were excluded if there was insufficient information to extract regarding participant characteristics, methods, and/or results. Titles, abstracts, and full-text articles were screened for eligibility by two independent reviewers (JW, SJ); discrepancies were resolved by a third independent reviewer (JC).

Study Appraisal

Randomized controlled trials (RCTs) were evaluated for methodological quality using the Physiotherapy Evidence Database (PEDro) tool (Table 1).[40] The PEDro tool consists of 11 items, each answered with a "yes" (score=1) or "no" (score=0). The tool yields a maximum score of 10, as the first item is not used in calculating the final score. Total scores were used to categorize RCT quality as poor (<4), fair (4-5), good (6-8), or excellent (9-10).[41] PEDro scores were determined by two independent reviewers (JW, SJ); discrepancies were resolved by a third reviewer (JC).

Insert Table 1 about here

Data Extraction, Synthesis, and Analysis

Study characteristics (i.e., author(s), year of publication, country of origin, study design, and sample size), participant characteristics (i.e., age, sex, stroke onset, stroke type, and lesion side), treatment protocols, and results were extracted from the included studies and organized into tables. Results of studies that examined the same outcome measures were pooled to form conclusions regarding the effectiveness of HIIT.

Outcome Measures

Fitness

Peak oxygen consumption (VO_{2peak}) is the most common measure of aerobic capacity across populations.[42] The value is determined by calculating the highest value of oxygen consumption (millimeters per minute, per kilogram of body weight) reached across repeated graded exercise tests, which has demonstrated reliability and validity in stroke.[43,44]

Ventilatory threshold (VT1) is a measure of the upper intensity limit of exercise,[45] and has demonstrated reliability and validity in stroke.[46] It represents the point at which ventilation increases at a faster rate than oxygen consumption, and thus the transition from aerobic to anaerobic metabolism.[45]

Walking economy (C_W) is a measure of the metabolic cost of walking.[6] The value is determined by measuring steady-state oxygen consumption at a self-selected walking speed, which has demonstrated reliability and validity in stroke.[47,48] Fractional utilization is the quotient of C_W over VO_{2peak}.[49]

Mobility

10-Meter Walk Test (10MWT) is a measure of walking speed,[50] and has demonstrated reliability and validity in stroke.[51,52,53] It assesses the time for a participant to complete a 10 meter straight line at maximum walking speed, which is often reported in meters per second (m/sec). The results of the 10MWT can be used to determine cadence (steps / minute) and stride length (speed / cadence).[54]

6-Minute Walk Test (6MWT) is a measure of walking endurance,[55] and has demonstrated reliability and validity in stroke.[52,56] It assesses the distance that a participant is capable of walking in a straight line within 6 minutes.

Timed Up and Go Test (TUGT) is a measure of functional mobility,[57] and has demonstrated reliability and validity in stroke.[52,58] It assesses the time for a participant to stand from a seated position, walk three meters away, turn around, walk three meters back, and then sit down.

Berg Balance Scale (BBS) is a measure of static and dynamic balance in sitting and standing,[59] and has demonstrated reliability and validity in stroke.[60,61] It assesses performance on 14 items, each on a 4-point scale for a total score of 56.

Rivermead Motor Assessment (RMA) is a measure of motor function,[62] and has demonstrated reliability and validity in stroke.[63] It assesses participant performance on 13 items of gross function, 10 items of trunk and lower limb function, and 15 items of upper limb function, each on a 1-point scale for total scores of 13, 10, and 15, respectively.

Functional Ambulation Categories (FAC) is a measure of walking ability,[64] and has demonstrated reliability and validity in stroke.[65] It assesses how much human support a participant requires when walking, with or without assistive devices, on a 6-point scale (0 to 5).

Safety

Safety was assessed in terms of reported side effects and adverse events. Side effects are defined as "any unintended effect" of an intervention that occurs within its normal parameters and is related to the properties of the intervention.[66] Adverse events are defined as "any untoward medical occurrence" that occurs during treatment with an intervention "but does not necessarily have a causal relationship" with the intervention.[66]

Results

Study and Participant Characteristics

Six articles met inclusion criteria (Figure 1). Study and participant characteristics for three pre-post studies[67-69] and three RCTs[70-72] are presented in Table 2. All RCTs were rated as good quality according to PEDro score (PEDro=6-8). The total pooled sample size of all included studies was 140, with a mean study sample size of 23. There were 97 males and 43 females across all studies. The mean age ranged from 49 to 71 years across studies, with an overall mean age of 60 years. The mean stroke onset ranged from 13 days to 7 years across studies, with an overall mean onset of 2 years. Participants were in the acute phase of stroke (<1 month) in one study,[71] in the subacute phase (1-6 months) in one study,[72] and in the chronic phase (>6 months) in four studies.[67-70] A total of 93 participants had ischemic stroke and 31 had hemorrhagic stroke; one study[67] did not report type of stroke. A total of 69 participants had left hemispheric strokes and 43 had right hemispheric strokes; one study[71] did not report hemisphere of stroke. As per inclusion criteria, all subjects were capable of walking independently and performing stress testing.

Insert Figure 1 about here

Insert Table 2 about here

Protocols

HIIT protocols varied across studies with duration ranging 20 to 30 minutes per session, frequency ranging 2 to 5 times per week, and length ranging 2 to 8 weeks in total. Assessments in each study were conducted at baseline and at the completion of intervention. Five studies[67,69-72] delivered HIIT on a treadmill, while one study[68] delivered HIIT on a stationary bicycle.

In three treadmill studies,[70-72] intense interval parameters were performed at maximum tolerated speed, which was increased or decreased each subsequent interval if the previous interval was completed successfully or unsuccessfully, respectively. In two treadmill studies,[67,69] intense interval parameters were performed at 85-95% peak heart rate (HR_{peak}), with intensity adjusted by both speed and incline. In the one cycling study,[68] intense interval parameters were performed at 80% maximum workload, with intensity adjusted by mechanical resistance. These high intensity parameters were achieved by participants in each of studies. The duration of intense intervals ranged from 30 seconds to 4 minutes across studies.

Recovery interval parameters were active movement in three studies[67-69] and inactive rest periods in three studies.[70-72] The duration of recovery intervals ranged from 30 seconds to 4 minutes. One study[72] had a recovery period that lasted until resting heart rate was achieved, and thus did not specify duration. Four studies[67,69,70,72] reported a warmup period before the study, ranging from 3 to 15 minutes in duration. Three studies[67,69,70] reported a cooldown period after the study, ranging from 2 to 5 minutes in duration.

All three RCTs[70-72] compared HIIT with treadmill training at a lower intensity and without intervals. Boyne et al.[70] provided moderate-intensity continuous training, which involved walking at a speed adjusted to maintain 45-50% heart rate reserve. Lau et al.[71] provided steady-speed training, which involved walking at the fastest overground speed. Pohl et al.[72] provided limited progressive training, which involved assisted walking that was increased by 5% of maximum tolerated speed each week. The latter study[72] also provided conventional gait training, which involved therapy based on Bobath concepts and proprioceptive neuromuscular facilitation.

Insert Table 3 about here

Fitness

VO_{2peak} was examined in four studies. Three of the studies[68-70] found significant improvements from baseline following HIIT, while one study[67] found no improvement. When compared to moderate-intensity continuous training, however, Boyne et al.[70] found that HIIT did not significantly improve VO_{2peak}.

VT1 was examined in one study. The study[70] reported significant improvements from baseline following HIIT, and that these improvements were significantly greater when compared to moderate-intensity continuous training.

C_W was examined in two studies. Both studies[69,70] found significant improvements from baseline following HIIT. However, Boyne et al.[70] reported that these improvements were not significant when compared to moderate-intensity continuous training. As well, the study found that fractional utilization was significantly improved from baseline following HIIT, which was significantly greater than the improvements achieved with moderate-intensity continuous training.[70]

Insert Table 4 about here

Mobility

10MWT was used in four studies. All of the studies[69-72] reported significant improvements in speed from baseline following HIIT. Two of the studies[71,72] calculated cadence and stride length during the 10MWT, and both reported improvements from baseline following HIIT. Another study[68] used an extended version of the 10MWT (20 meters), but did not find significant improvements in performance from baseline following cycling HIIT.

Three RCTs[70-72] found significant improvements in 10MWT speed compared to all control conditions (i.e., moderate-intensity continuous training, steady speed training, limited progressive training, and conventional gait training). In addition, Pohl et al.[72] found that HIIT yielded significantly greater improvements in cadence and stride length than both limited progressive training and conventional gait training. However, Lau et al.[71] found that HIIT yielded significantly greater improvements in stride length, but not cadence, when compared to steady speed training.

6MWT was used in four studies. All of the studies[67-70] reported significant improvements from baseline following HIIT. However, Boyne et al.[70] found that there was no significant difference between HIIT and moderate-intensity continuous training at improving performance on the 6MWT.

TUGT was used in one study. The pre-post study[69] reported significant improvements from baseline following HIIT.

BBS was used in one study. The RCT[71] reported significant improvements from baseline following HIIT, but the results were not significant when compared to steady speed training.

RMA was used in one study. The pre-post study[67] found significant improvements from baseline following HIIT; however, only gross function was assessed.

FAC was used in one study. The RCT[72] found significant improvements from baseline following HIIT, which were significantly greater than those with limited progressive training and conventional gait training.[72]

Insert Table 5 about here

Safety

A variety of safety measures were utilized during the HIIT protocols. All studies reported monitoring of heart rate, blood pressure, and perceived exertion, which guided the intensity and duration of intervals. All five treadmill studies[67,69-72] permitted the use of handrails and orthotic devices during training, and four studies[67,70-72] provided body-weight support from an overhead harness system. The cycling study[68] used large foot pedals to ensure maximum grip, as well as large straps to secure feet to the pedals.

Side effects and adverse events were recorded in five studies.[67,69-72] Two studies[69,71] reported that no side effects or adverse events occurred that were associated with HIIT, while another study[70] reported that no side effects or adverse events had occurred that were serious or unanticipated. In three studies,[67,70,72] side effects that were associated with HIIT included fatigue, light-headedness, and joint/muscle pain. Only one study[67] reported an adverse event during HIIT, which was a minor fall that did not result in serious injury.

Discussion

HIIT Protocols

Current best practice guidelines for stroke rehabilitation recommend MICE to improve fitness and mobility.[33] The suggested protocol involves 20-60 minutes of exercise, 3-7 days per week such that 40-70% VO_{2peak} or 50-80% HR_{peak} is achieved,[33] although this type of exercise may not be optimal for some individuals. HIIT protocols are advantageous in that they can be adapted to best suit the needs and capabilities of the individual; the modality, interval type, intensity, frequency, and duration can all be modified. The personalization of HIIT has the potential to improve enjoyment of, and thus adherence to, exercise.[73]

HIIT is often performed using treadmill equipment in the general population.[74] The treadmill may be the best modality for use in stroke rehabilitation given its task-specificity for walking, particularly when used for improving mobility. However, other modalities such as a stationary bicycle may be preferable for individuals with specific physical limitations. Other advantages of using a treadmill or stationary bicycle are that the intensity can be easily modified according to workload. Both of these modalities appeared to be effective for implementing HIIT. Intervals of HIIT can be short (15-60 seconds at 100-120% VO_{2peak}; 1:1 recovery ratio),[70-72] long (3-4 minutes at 80-90% VO_{2peak}; 1:1-4:3 recovery ratio),[67,69] or of low volume (10-30 seconds at 100% VO_{2peak}; 1:4-1:12 recovery ratio).[68] The current review did not have sufficient evidence to determine whether one interval type was more or less effective than another type. Intensity of intervals is often determined through VO_{2peak}, although it has been suggested that intensity be based on workload, as it accounts for both aerobic capacity and metabolic cost.[75] The included studies utilized HR_{peak},[67,69] maximum tolerated speed,[70-72] and maximum workload[68] to determine intensity. While it may be difficult to sustain the target exercise intensity during HIIT sessions post stroke, participants were successful in achieving these levels.

Most of the HIIT training sessions in the included studies lasted for 30 minutes,[68,69,71,72] but HIIT was still found to be effective at 20-25 minutes.[67,70] Short training session duration is an attractive feature of exercise for individuals, particularly among older adults. In individuals over 60 years of age, it has been suggested that more time between sessions optimizes recovery and minimizes fatigue, at least in the initial weeks of the program.[76] The studies included for review provided HIIT between two and five times per week, and each were associated with improvement in at least one domain. Similarly, training programs ranged in length from two to eight weeks, and all demonstrated some level of improvement. These findings highlight the significant effects that can be incurred with relatively brief HIIT protocols post stroke.

Fitness

In stroke rehabilitation, aerobic exercise significantly improves cardiorespiratory fitness both in terms of aerobic capacity[77-79] and walking economy[79] when compared to non-aerobic exercise, with higher intensities being more effective in improving fitness.[80] The current review found that three of four studies[68-70] reported improved fitness as a result of HIIT, even with varying protocols. When compared to MICE, HIIT improved some aspects of fitness (e.g., VT1) but not others (e.g., VO_{2peak}).[70] Several potential mechanisms of HIIT in improving fitness have been suggested in the literature. These mechanisms include an increase in mitochondrial function[81] and/or calcium uptake in skeletal muscle,[82] which improves structural integrity and decreases fatigue, respectively. Increased oxidative capacity of skeletal muscle as a result of repeated intervals of deoxygenation[30] or improved systemic flow-mediated vasodilation[74] has also been proposed as a mechanism for improved fitness.

Mobility

Overground and treadmill gait training are common interventions for improving mobility in stroke rehabilitation. While they improve speed,[83] walking endurance,[83] and balance,[84] they are limited in that they do not necessarily incorporate aerobic exercise. Aerobic exercises used in stroke rehabilitation typically involve modalities such as treadmill, stationary bicycle, and recumbent stepper.[79] As a result of variances in the protocols applied and the outcomes used to assess mobility, conflicting findings have been reported as to whether aerobic exercise improves gait speed, walking endurance, and balance[77-79,85] when compared to conventional gait training.

The current review supported the notion that HIIT improves gait speed,[69-72] yielding greater improvements than MICE.[70-72] HIIT also improved walking endurance[67-70] and balance,[69,71] although MICE yielded similar improvements.[70,71] Several potential mechanisms for improved mobility have been proposed in the literature including increased corticospinal excitability[86] and neurotrophin expression,[87] which enhance motor learning.[88-90] Among individuals with stroke, aerobic exercise may also promote neuroplasticity[17,91] and neuroprotection.[92] Moreover, recovery intervals in HIIT may provide greater opportunity for mental practice and cognitive processing than MICE, which can result in greater retention of motor learning.[93]

Safety

When implementing a HIIT protocol in stroke rehabilitation, therapists may be concerned with the actual or potential risks to safety. Only one study[67] reported an adverse event (i.e., a fall), which did not result in injury and was not directly relatable to HIIT. All other side effects were non-notable and within range of what one would expect after performing exercise among older individuals post stroke (i.e., fatigue and joint/muscle pain). These findings may reflect the inherent safety of HIIT, and/or a cohort of high functioning individuals due to the inclusion/exclusion criteria of the studies. A safety analysis[94] reported that post-stroke HIIT was not associated with any cardiovascular events (e.g., hypotension, hypertension, arrhythmia) or orthopedic events (e.g., pain, falls).

Clinicians should conduct baseline medical screening and graded exercise stress testing before proceeding with HIIT.[33] Considerations should be made for ability to walk independently, with or without assistive devices, as well as for pre-existing cardiovascular or orthopedic risk factors. The studies included in the current review applied several objective monitors (e.g., heart rate, blood pressure) to maximize safety. However, subjective measures such as rating of perceived exertion may also be useful to monitor, since they allow for self-regulation and exercise adaptation.

Limitations

The current review only included a small number of studies, which were often performed in the pilot stage and thus had small sample sizes. The limited number of overlapping outcome measures and data provided meant that a meta-analysis could not be performed. Across the studies, subjects had different levels of stroke onset and baseline impairment. As well, there was considerable variation in the HIIT protocols applied in each study. Thus the heterogeneity of subjects and interventions must be accounted when considering the synthesis of the evidence.

Future Directions

There are several important avenues for future study of HIIT in stroke rehabilitation. Researchers should determine the subset of individuals who are most likely to respond to and benefit from HIIT post stroke. Varying HIIT protocols could be studied by comparing different training parameters (e.g., short-interval, long-interval, low-volume) and exercise modalities (e.g., treadmill, bicycle, stepper). Researchers should also compare the effectiveness of HIIT to other training programs (e.g., high-intensity continuous aerobic training, progressive aerobic training). Furthermore, the impact of HIIT on clinically important outcomes (e.g., functional independence, quality of life) could be explored using reliable and validated measures.

Conclusions

Overall, there is preliminary evidence to suggest that HIIT may be an effective rehabilitation intervention for improving some aspects of cardiorespiratory fitness and mobility post stroke. To better understand the effectiveness of HIIT in stroke rehabilitation, RCTs with large samples and high methodological quality are necessary.

Abbreviations

10MWT: 10-Meter Walk Test

6MWT: 6-Minute Walk Test

BBS: Berg Balance Scale

C_W: walking economy

FAC: Functional Ambulation Categories

HIIT: high-intensity interval training

HR_{peak}: peak heart rate

MICE: moderate-intensity continuous exercise

PEDro: Physiotherapy Evidence Database

RCT: randomized controlled trial

RMA: Rivermead Motor Assessment

TUGT: Timed Up and Go Test

VO_{2peak}: peak oxygen consumption

VT1: ventilatory threshold

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Figure Legends

Figure 1. Study selection process.

Appendix

Medline

[(MH “Stroke”) OR (MH “Stroke Rehabilitation”)] AND [(MH “Exercise Therapy”) OR (MH “High-Intensity Interval Training”)]

Embase

(MH “Cerebrovascular Accident”) AND [(MH “Treadmill Exercise”) OR (MH “High Intensity Interval Training”)]

CINAHL

(MH “Stroke”) AND [(MH “Aerobic Exercises”) OR (MH “Therapeutic Exercise”) OR (MH “Gait Training”)]

PsycINFO

(MH “Cerebrovascular Accidents”) AND [(MH “Athletic Training”) OR (MH “Exercise”)]

Scopus

(“stroke” OR “cerebrovascular accident”) AND (“interval training” OR “intermittent exercise” OR “treadmill training”) AND (“high intensity” OR “speed dependent”)