High-intensity interval training is feasible, credible, and clinically effective in the early subacute stroke stage in the low-income country of Benin

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Abstract

Background and objective: High-intensity interval training (HIIT) has been shown to benefit stroke patients when implemented three months post-stroke. However, its feasibility and clinical effectiveness have not been assessed early post-stroke (within 30 days) in a low-income country. Therefore, this study examined HIIT's feasibility and clinical effectiveness in the early subacute post-stroke stage in Benin.

Methods: This was a prospective interventional study comprising a HIIT program executed on a recumbent bike, 3x/week, 20-30 min/session for 6 weeks, added to conventional physiotherapy. The primary outcomes were protocol feasibility, credibility and expectancy assessed with credibility and expectancy questionnaire. A maximal exercise test, 6-min walking test (6MWT), 10-m walking test (10mWT), Berg balance scale (BBS), and five repetitions sit-to-stand test (5R-STS) were performed before and after the training program.

Results: Ten outpatients, median age [P25-P75]: 63.5 [56.7-71.2] years; time since stroke: 15.0 [9.7-21.0] days commenced and completed all training sessions without serious adverse events. High scores were observed on the Credibility subscale at admission (median 27.0 [25.7-27.0]), which remained so after intervention (median 26.5 [25.7-27.0]). Expectancy subscale scores were high at admission (median 25.5 [24.0-27.0]) and post-training (median 25.5 [24.5-27.0]). At completion of intervention, peak workload ($p< 0.001$), BBS ($p< 0.001$), 6MWT ($p< 0.001$), 10mWT ($p< 0.001$), and 5R-STS ($p= 0.004$) were all improved.

Conclusion: HIIT is feasible and safe in the early subacute post-stroke stage and is perceived by patients as highly credible, meeting their expectations of recovery on admission. Moreover, HIIT appears to be a potentially powerful stimulus for improving physical functions early post-stroke.

Trial registration: ClinicalTrials.gov registration number: NCT05804006

Keywords: Acute stroke, High-Intensity Interval Training, Feasibility, Credibility, Expectations

Introduction

Stroke is the second leading cause of death and a major cause of disability worldwide.[1] In contrast to high-income countries, where age-standardized stroke incidence and mortality are declining significantly, 70% of global strokes and 87% of stroke-related deaths and disability-adjusted life years occur in low- and middle-income countries (LMICs).[2] In Africa, many people suffer a stroke between the fourth and sixth decade of life, with serious consequences for the individual, his or her family, and society.[3] Strokes in younger people tend to result in a greater loss of self-esteem and socio-economic productivity than in older people.[3] Recent articles have reported that the one-month case-fatality rate is twice as high in Africa as in Europe,[4,5] most likely due to the increased availability of early post-stroke treatments and improved inpatient care in high-income countries (HICs).[4] An impaired aerobic exercise capacity is common in the first six months after stroke, particularly in the first month after stroke, limiting survivors' ability to walk and perform daily activities, leading to physical inactivity and a sedentary lifestyle.[6,7] It has been demonstrated that without exercise-based rehabilitation most patients do not spontaneously recover their aerobic exercise capacity in the first 6 months post-stroke.[7,8] On the other hand, an improved aerobic exercise capacity contributes to independence in self-care activities and participation in meaningful activities, such as work and social life, which are often limited after a stroke.[9] More recently, the WHO has launched a set of interventions for stroke rehabilitation, recommending assessment of exercise capacity on a cycle ergometer and fitness training after stroke.[10]

Exercise therapy, including aerobic exercise training (AT), is highly recommended after stroke in HICs to promote recovery, including aerobic exercise capacity and muscle strength, especially when implemented from the first week until the first-month post-stroke because of the increased neuronal plasticity during this period.[11–13] However, a recent observational study has reported that AT is rarely delivered during the first month post-stroke in Benin, a low-income country.[14] So, the introduce of a new approach such as high-intensity interval training (HIIT) using a recumbent bike could be culturally accepted by patients and would add value to the technical picture of stroke rehabilitation professionals in a low-income country like Benin. In exercise prescription, moderate-intensity continuous exercise training (MICT, 40–60% HR reserve or 64–76% peak HR or RPE of 4–5/10 or RPE 12–13/20) is generally recommended after stroke[11,15] with greater benefits on aerobic exercise capacity[9,16] compared to conventional rehabilitation approaches which include low-intensity exercise training. Indeed, recent evidence suggest that a high dose of AT (duration ≥ 120 min/week; intensity: ≥

60% of heart rate reserve) is a more effective strategy to facilitate walking endurance in chronic stroke than low or moderate doses.[17,18] Furthermore, in the last decade, HIIT has emerged as a powerful time-efficient alternative to MICT to enhance neuroplasticity, aerobic exercise capacity[19], walking speed, and walking endurance in late subacute and chronic stroke.[20,21] HIIT is characterized by bursts of high-intensity endurance exercise interspersed with recovery episodes and aims to maximize exercise intensity with less time commitment and total exercise volume.[21,22] There are many excellent reviews on the effects of HIIT on exercise capacity and general health in healthy and clinical populations, and on the mechanisms underlying these effects.[22–24] The body of the literature reported that neuroplasticity peaks at one-month post-stroke,[12] and HIIT has the potential to contribute to enhanced neuroplasticity and motor recovery post-stroke, as higher exercise intensities are required to enhance the expression of neurotrophins (e.g. myokines such as lactate, interleukin-6, cathepsin-B and brain-derived neurotrophic factor [BDNF]) and stimulate cerebral perfusion, which ultimately augment neural repair processes.[21,23] Therefore, implementing HIIT within the first-month could be the most beneficial for stroke survivors.

Previous studies have shown that HIIT is feasible and safe for stroke patients, when implemented at three months post-stroke.[20,25,26] However, the feasibility and potential clinical effects of HIIT during the first month following stroke remains to be studied. The feasibility of the HIIT program in patients with significant motor deficits, such as in stroke, is essential to assess aspects such as recruitment, retention, and adherence to the intervention, but also practical aspects in the clinic, including the safety of the intervention, appropriate dose, and potential treatment effect. The credibility of the therapy and the patient's expectation of improvement are increasingly recognized as important determinants of response and adherence to therapy.[27] "Therapy credibility refers to the extent to which a treatment makes sense, is believable, convincing and logical, whereas expectancy refers to improvements that patients believe will occur based on this particular treatment."[27] It has been demonstrated that positive expectations are associated with better health outcomes after various treatments for several conditions, including stroke, Parkinson's disease, mood and anxiety disorders.[28] Knowing the level of patient expectation and credibility to therapy would allow practitioners to motivate patients for better results. The primary aim of the current study was to investigate the feasibility of HIIT early post-stroke using a recumbent bike in a low-resource setting. The secondary aim was to explore clinical effects of combining HIIT on top of conventional physiotherapy in the early subacute post-stroke stage in Benin.

2. Methods

2.1 Study design, setting, and ethical considerations

This study was a prospective interventional study conducted at the University Hospital of Parakou in Benin from December 1, 2022 to March 31, 2023. The study protocol was approved by the local Biomedical Ethics Committee of the University of Parakou, in Benin, under the number: 0557 CLERB-UP/P/SP/R/SA. After presenting the study protocol outline, we received signed consent from the participants under the Declaration of Helsinki. The study was registered at Clinicaltrials.gov (NCT05804006).

2.2 Participants and eligibility criteria

Potential participants were identified from the Unit of Neurology and NeuroRehabilitation of the University Hospital of Parakou by consulting admission records.

Inclusion criteria were: (i) first episode from an ischemic or hemorrhagic stroke confirmed by CT scan; (ii) within the first month after the event; (iii) muscle strength of the affected leg defined by the Motricity Index[29] score between 14 and 19, i.e., between 2 and 4 on the Medical Research Council scale; (iii) modified Ashworth[30] score of 0 or 1, indicating no spasticity or slight spasticity over the affected lower limb, respectively (iv) able to walk at least 5 meters independently with or without assistive devices and understand simple instructions; (v) resident in Parakou or its surroundings and (vi) wish to participate in the hospital program

Exclusion criteria were: patients whose medical records reported (i) uncontrolled cardiac arrhythmias (e.g. atrial fibrillation, ventricular tachycardia), heart failure, or recent myocardial infarction, arteriopathy, (ii) primary orthopedic conditions (e.g., fractures, active rheumatoid arthritis), (iii) other neurological diseases (such as Parkinson's disease and Alzheimer's disease), and (iv) patients unable to perform a graded exercise test, i.e., unable to reach the target cadence of 50 rpm or exercise-induced asthma were excluded.

2.3. Intervention

The experimental intervention was preceded by 30 minutes of conventional physiotherapy, including 10 minutes of passive movement, stretching, and strengthening, 10 minutes of balance and postural awareness training, and 10 minutes of low-intensity overground walking, administered three times weekly for six weeks by an experienced physiotherapist.[14] The conventional physiotherapy was followed by a 15-min rest period, then the experimental protocol (Figure 1) consisting of a HIIT program on a recumbent bike R92 (SOLE Fitness; Salt Lake City, United States) was performed. Each HIIT session was preceded by 3 minutes of unloaded cycling as a warm-up and ended with 3 minutes of lower limbs muscle stretching. Each session associated two successive phases: 1-min at 70% of the peak workload interspersed with 4-min at 30% for weeks 1 and 2 (4 repetitions of 5-min each). As tolerated, it increased by approximately 5 minutes every two weeks to reach 30 minutes from week 5 (6 repetitions). In patients with cardiovascular disease, 70% of the peak workload coincides with the second ventilatory, or anaerobic, threshold.[31] The training intensity progressed similarly by 5% peak workload two weeks as tolerated, reaching 80% of peak workload interspersed with 40% from week 5. The cycle cadence was at least 50 rpm. To reduce the risk of adverse events during HIIT training careful monitoring of heart rate (HR) and blood pressure (BP) has been implemented. HR was continuously recorded by the chest belt heart rate monitor during each HIIT session. BP was measured manually using an OMRON X3 electronic BP monitor (OMRON, Kyoto, Japan) before HIIT training, during training if any abnormal sensation was felt or reported by the patient (e.g., nausea, dizziness, excessive dyspnea). The upper limit of BP was set at 220 mm Hg for systolic pressure and 115 mm Hg for diastolic pressure, and the lower limit of BP was set at a drop in systolic BP > 10 mm Hg.[32] In addition, the sessions were conducted in the presence of a medical doctor. The same physiotherapist supervised all sessions individually, providing the same verbal encouragement as "Go, Go, you can do better." Depending on the physical condition of each participant, a break could be taken during the cycling if needed. Participants were allowed to make up a missed session to complete the 18 scheduled sessions.

[Insert Figure 1 about here]

2.4. Assessment and outcome measures

Participants were assessed at two time points: baseline (at enrolment) and at 6 weeks (immediately post-intervention).

2.4.1 Baseline data

Demographic (e.g., age, sex) and clinical characteristics (e.g., age, type of stroke, paretic side) were collected from the patients' medical records and the following tests were performed only on admission:

We used the National Institutes of Health Stroke Scale (NIHSS)[33] to assess the severity of the stroke. The NIHSS comprises 11 items, each scoring a specific ability between 0 and 4. The maximum possible score is 42, with the minimum score being 0. Stroke severity was stratified based on NIHSS scores as follows: Very Severe (score >25); Severe (score:15 – 24); Moderate (score: 5 – 14); and Mild (score: 1 – 4).[33]

The cognitive function was screened with the Mini-Mental State Examination (MMSE).[34] The MMSE scale contained an 11-question measure that tests five areas of cognitive function: orientation, registration, attention and calculation, recall, and language. The maximum score is 30. A score of 23 or lower is indicative of cognitive impairment.[34] For participants who could not read, a parent who could read was called in to translate the instructions.

The strength in the lower extremities was assessed with the Motricity Index (MI) scale.[35] The MI is a simple, brief measure of general motor function after stroke. In the lower limb, the three movements were hip flexion, knee extension, and ankle dorsiflexion. The score for each movement ranges from 0 (no movement) to 33 (normal power). The three scores were summed and added by one, and the total score was ranged from 0 (complete paresis) to 100 (normal strength).[35]

We used the modified Ashworth scale[36] (MAS) to evaluate lower limb muscle strength and spasticity. The MAS is the most widely used clinical scale to measure muscle tone increase. The MAS scores range from 0 to 4, where lower scores represent normal muscle tone and higher scores represent spasticity.

The modified Rankin Scale (mRS) was used to measure the degree of overall disability. The mRS is the most widely used outcome measure in stroke clinical trials to quantify functional outcome.[37] The scale comprises seven levels, from 0 to 6, with higher scores indicating greater disability and where 2 is estimated as the MCID.[37]

2.4.2 Outcome measures

The following measurements were carried out before and immediately after the intervention, with the exception of aspects relating to feasibility.

2.4.2.1 Primary outcomes

The primary outcomes were protocol feasibility, credibility and expectancy towards recovery.

The protocol feasibility aspects, including recruitment rates (eligible population / consented population x 100), program adherence (attended sessions / total number of sessions x 100), and the safety i.e., the frequency of adverse events.

The treatment credibility and participant expectations for improvement were assessed with the French version of the Credibility and Expectancy Questionnaire (CEQ).[27] The French CEQ version has been shown to have high internal consistency for credibility and expectancy factors with Cronbach's $\alpha = 0.97$ and 0.95, respectively. Moreover, the CEQ showed excellent test–retest reliability for credibility ($r = 0.81$) and expectancy ($r= 0.80$) factors.[27] The CEQ includes a Credibility subscale (3 items) and an Expectancy subscale (3 items). The Credibility subscale has a 1–9 rating scale (1 "not at all" to 9 "very") for a total sub-score ranging from 3 to 27. The Expectancy scale has a 0-100% scale, and item 2 has a 1-9 rating scale for a total sub-score ranging from 3 to 27 after transforming the percentage scales.[28] A moderate score ranges between 13.50 to 20.25; scores above 20.25 are considered high.[38] The CEQ was administered to participants before and after the exercise program by a physiotherapist not involved in the study to prevent desirability bias.

2.4.2.2 Secondary outcomes

Maximal effort

A progressive intensity maximal effort cycling test[39] was performed in a recumbent bike R92 to determine each participant's peak work rate and to provide individually tailored training according to standard aerobic training recommendations.[11] The ramp protocol includes a 3-minute warm-up at 10W at a target cadence of 50 rpm, followed by progressive 5-W increases in work rate every minute, as described in detail elsewhere.[39] The work rate in watts, heart rate (HR), and rate of perceived exertion (RPE) were taken during the last 15 seconds of each stage. The HR was taken by the SOLE chest strap HR monitor while RPE was evaluated with the Borg scale 6-20.[40]

Balance

The Berg Balance Scale (BBS), which has demonstrated reliability and validity in stroke, was used to assess functional balance.[41] It is a 14-item list with each item consisting of a five-point ordinal scale ranging from 0 to 4, with 0 indicating the lowest level of function and 4 the highest. The minimum score is 0, and the maximum score is 56. A score of 56 indicates functional balance and a < 45 indicates a higher risk of falling. The minimal clinically important difference (MCID) is 5 points for early subacute stroke people.[41]

Walking endurance

The 6-minute walk test (6MWT) was used to evaluate walking endurance.[42] The 6MWT is a measure of walking endurance that has demonstrated reliability and validity in stroke.[42] It assesses the distance a participant can walk as fast as possible for 6 min on a 30 m straight line with the option to stop for fatigue at any point. The estimated MCID is 44 m for subacute stroke people.[42]

Walking speed

The 10-meter Walk Test (10mWT) assessed the walking speed. The 10mWT is a performance measure used to assess walking speed in meters per second over the middle 10 meters of a 14-meter course.[43] Participants were instructed to walk the distance at a comfortable speed. They may use any assistive device (e.g., cane or walker) that they usually use. The time to cover the set distance was documented. The estimated MCID is 0.16 m/s for early subacute stroke.[43]

Lower limb muscle strength

We evaluated functional lower extremity strength with the 5-Repetition Sit-To-Stand test (5R-STS), a valid and reliable functional tool for use with stroke.[44] The 5R-STS test measures the time to complete five repetitions of the sit-to-stand maneuver. Participants unable to complete five repetitions within 1-min were given a score of 60 s, in line with a previous study.[44] The MCID for stroke patients with limited community ambulators is 3 s, and those of the household ambulators decreased from 1.9 s to 0.72 s.[44]

2.6 Sample size estimation

This study was a phase I safety and feasibility trial. Hertzog[45] suggested that 10–20 patients are adequate to assess the feasibility of a pilot study. Based on the number of beds and the flow of patients coming from remote areas and immediately returning home, far from the trial site after discharge from hospital, we estimated that at least 16 participants would be recruited in 16 weeks.

2.7 Data analysis

Data were analyzed using IBM SPSS v26.0 (Chicago, United States). Patient characteristics, CEQ credibility, and expectancy scores, as well as functional outcome measures, are presented as mean (SD), median (interquartile range [IQR]), and number (%), as appropriate. Wilcoxon signed-rank tests compared the changes in CEQ, BBS, peak workload 10mWT, 6MWT, and 5R-STS scores between admission and post-training. Percentage increase for continuous variables was calculated using the difference between post-training and baseline scores divided by the baseline score. Statistical significance was set at 5% ($p < 0.05$).

3. Results

Figure 2 shows the flow chart of inclusion and follow-up. Of the 14 participants screened for this study (Figure 2), two patients were excluded because they were unable to reach the target cadence of 50 rpm during the test, and an additional two participants withdrew voluntarily as they opted for traditional treatment, based on family decisions. Finally, ten outpatients were included in the analysis.

Participant characteristics are presented in Table 1. Participants' age (median [P25-P75]) was 63.5 (56.7-71.2) years with a sex ratio 1.5 in favor of men. Most participants (90%) had an ischemic stroke, and six (60%) had a moderate severity. Most participants (90%) had moderate to severe disabilities (mRS score ≥ 3).

[Insert Figure 2 about here]

Feasibility of high-intensity interval training exercise early poststroke

Of the 14 subjects potentially eligible for the study, 12 consented to participate, for a recruitment rate of 85.7%. All participants attended the program after hospital discharge and completed the 18 scheduled sessions. This resulted in a 100% program adherence rate. No major adverse events such as cardiovascular events (e.g., vasovagal syncope, hypertensive or hypotensive responses) or orthopedic injury (e.g., fall, ankle sprain) were detected or reported by participants during the 6-week program. The study showed two minor adverse events, namely knee pain on the non-paretic side, which was relieved within minutes of the session.

Table 2 shows the distribution of CEQ scores at admission and follow-up. High scores were observed on the Credibility subscale at admission (median 27.0 [25.7-27.0]) and follow-up (median 26.5 [25.7-27.0]) with no significant changes over time between item scores and the credibility subscale score. Scores on the Expectancy subscale were high at admission (median

25.5 [24.0-27.0]) and follow-up (median 25.5 [24.5-27.0]) with no significant changes over time between item scores and the Expectancy subscale score.

Changes in outcome measures

Figure 3 shows that all participants improved their exercise capacity (fig. 3a) and peak heart rate (fig. 3b) during follow-up. There are no non-responders to the exercise test at different time point. There is significant increase in workload capacity (mean change of 56.2%, $p< 0.001$), peak heart rate (mean change of 13.8%, $p= 0.002$) at completion of interventions, in contrast to patient-perceived exertion (Table 3).
Changes in functional outcome measures are reported in Table 3, while individual changes are presented in Figure 4.

We found that BBS scores improved in all participants after interventions (figure 4a). The BBS overall score was median 41.0 (34.0-48.2) at admission vs 55.0 (53.5-56.0) at follow-up (mean 34.1%, $p< 0.001$). Nine (90%) patients reached MCID for BBS at post-training.

Figure 4b shows that all patients spent less time performing the 5R-STS test. Findings showed a significant difference (mean decrease 55.0%, $p= 0.004$) between 5R-STS scores at admission and post-training. Nine (90%) patients reached MCID for 5R-STS at post-training.

Compared to admission, the walking distance in the 6-minute walk test almost doubled in all participants at follow-up (figure 4c) with a significant increase (mean change 261%, $p< 0.001$). All participants (100%) achieved MCID for 6MWT at post-training.

Concerning walking speed, almost all participants had a double walking speed at completion of interventions (Figure 4d). A significant improvement in walking speed was found (mean change 300%, $p< 0.001$). All participants (100%) achieved MCID for 10mWT at post-training.

[Insert Figure 3 about here]

[Insert Figure 4 about here]

[Insert Table 3 about here]

4. Discussion

The current intervention examined the feasibility and efficacy of combining high-intensity interval training on top of conventional physiotherapy in early subacute stroke patients. The main findings of this study are that adding a HIIT program to conventional physiotherapy is feasible, safe, highly credible, and meets patients' expectations for functional recovery. In addition, the HIIT program showed promising prospects for improving aerobic capacity, balance, walking speed, walking endurance, and the ability to sit-to-stand early after stroke, especially in patients with mild to moderate stroke.

All ten patients who started the program completed all 18 training sessions. Our results suggest that the participants appreciated the individual adaptation of the training to their initial peak workload and the recumbent bike on which the program was performed. The adherence is likely higher because it was combined with already scheduled physiotherapy. The adherence for HIIT program alone may have been lower. Although two participants experienced sporadic knee pain on the non-hemiparetic side, the intervention program can be considered safe as no serious adverse events, including orthopedic injury and cardiovascular events, occurred during the six-week intervention. The program's safety in a physically inactive population with a high risk of falls can be attributed to the interval training mode, which promotes discontinuity of effort, and the sitting modality used, which promotes trunk control and prevents falls during training. Seated modality types have been reported to be safer than a treadmill and allow people with a wide range of functions to participate in a HIIT program.[21] A systematic review and meta-analysis reported falls and skin injuries when implementing high-intensity treadmill exercise.[46]

Concerning the credibility of the treatment, the patient's score was very high at admission and after 6-week intervention. These results align with a previous study of patients with neurological diseases, including stroke, multiple sclerosis, and spinal cord injury.[47] Our results suggest that patients believe in the added value of HIIT for early post-stroke rehabilitation. However, two patients had not agreed to participate in the rehabilitation program, as they were obliged by their families to follow traditional medicine. This is not surprising, as in sub-Saharan Africa, and particularly in Benin, the conception and acceptance of health condition is strongly influenced by culture,[48] defined as "the integrated patterns of human behavior that include the language, thoughts, communications, actions, customs, beliefs, values and institutions of racial, ethnic, spiritual or social groups."[49] The supernatural conception (e.g. bewitchment, divine punishment) of a health condition modifies people's experiences and reactions and shapes their understanding of health, symptoms, attitudes towards disability, and treatment options.[48,50] A recent review has reported that spiritual and traditional beliefs play an important role in stroke rehabilitation in sub-Saharan Africa.[49]

Our finding that the median (26.5/27.0) expectancy score towards recovery after HIIT was very high, in line with a previous study[28] in subacute stroke patients (median 21.6/27.0). In contrast to two previous studies[28,47], which showed that expectancy scores were slightly lower at follow-up than baseline expectancy scores (but not significantly so), the current study showed similar expectancy scores at admission and 6-week follow-up. Our results showed that patients had high expectations of the treatment protocol at enrolment. This could have motivated them to actively engage in the treatment process in order to achieve the desired goals. The high rate of adherence noted at the end of the programme seems to illustrate the patients' initial level of expectation. The importance of expectations and their influence on outcomes have been demonstrated in people with Parkinson's disease who have undergone deep brain stimulation.[51]

The finding that combining HIIT with conventional physiotherapy significantly improved aerobic capacity (as measured by peak work rate) after stroke is in line with those of several earlier studies in the chronic phase of stroke. Three trials[20,52,53] reported significant beneficial effects of HIIT on aerobic capacity. In contrast, one trial[54] reported no effect of HIIT on aerobic capacity. However, the latter implemented a lower volume of sessions (25min x 2 times/week, 6 weeks) than the other trials[20,52,53] (20-30min x 3 times/week, 4-8 weeks). Although natural recovery is possible within the first three months after stroke, it has been reported that most patients do not spontaneously recover their aerobic capacity until 6 months post-stroke.[7] Our results show that aerobic capacity can improve in the early subacute stage of stroke, which would have a positive impact on functional recovery and accelerate reintegration into normal life in the early post-stroke period. Improving aerobic capacity has been shown to reduce energy requirements for walking, reduces fatigue and activity intolerance, and promotes participation in activities of daily living.[6,9] Several potential mechanisms behind the improvement in cardiovascular health are reported in the literature, including the increase in mitochondrial biogenesis essential to the structural integrity of skeletal muscle, which occurs after HIIT thanks to the increase in PGC-1α (peroxisome proliferator-activated receptor gamma coactivator 1-alpha), which correlates with the improvement in cardiorespiratory fitness.[21,23] Unlike the current study, peak oxygen uptake

(VO2peak) was the main aerobic capacity measure used in the aforementioned trials[20,52,54] while one study[53] assessed it with peak work rate. Assessing VO2peak to objectify aerobic capacity requires expensive equipment (e.g., open-circuit spirometer) and training of the therapists compared to using peak workload method. The latter approach would be more suitable for low-income countries such as Benin, as most rehabilitation services are not equipped in these countries compared to HICs.[55] In addition, measuring VO2peak in the early subacute setting is a particularly arduous task due to various factors such as neuromotor limitations of the lower limbs, lack of trained professionals and specialized equipment, and extreme fatigue of the participant.[56] The vast majority of cardiovascular rehabilitation guidelines recommend that aerobic training intensity is based on maximal effort indices, including % VO2peak, % peak work rate, % HRpeak and % HR reserve.[31,57]

Our study found significant improvement in all the functional outcome measurements used, such as the 6MWT, 10mWT, BBS and 5R-STS. These results are not surprising, as our recent observational study showed a significant improvement in motor function and walking ability following conventional physiotherapy at one-month post-stroke.[14] Nevertheless, these results could also be induced by natural recovery, as reported in the literature.[12] Our finding that combining HIIT with conventional physiotherapy is beneficial in improving post-stroke balance aligns with the body of literature. A systematic review[25] evaluating the effectiveness of HIIT after stroke reported a significant improvement in BBS. Also, a recent randomized controlled trial[58] has reported that HIIT produced a significant improvement in BBS in the late subacute and chronic phases of stroke. In contrast to MICT,[17,59,60] our results show that HIIT performed on recumbent bike could be considered an effective intervention for improving post-stroke balance. The body of literature indicates that HIIT has the potential to contribute to enhance neuroplasticity and motor recovery poststroke, as higher exercise intensities are required to increase the expression of brain-derived neurotrophic factor and insulin-like growth factor I, neurotrophins that modulate neural repair processes.[21,61]

Our results showed that HIIT plus conventional physiotherapy significantly improved 5R-STS time, suggesting improvements in lower limb muscle strength and balance ability, which are independently correlated with 5R-STS time in subjects with stroke.[62] Although STS movement is essential to independence and commonly affected by stroke, trials evaluating the effects of AT on STS ability are very rare. A longitudinal cohort study reported found that STS-related functioning improved significantly in the first year after stroke, with the most improvement occurring during the first 12 weeks.[63] Nevertheless, HIIT has been shown to promote motor recovery after stroke.[21]

The findings that combining HIIT with conventional physiotherapy significantly improved walking distance and walking speed are in line with previous studies.[25,58] It has been shown that walking endurance is associated with peak aerobic capacity[6] while walking speed is highly associated with the muscle strength of the affected leg.[64,65] In contrast to our finding, a meta-analysis showed that high-intensity aerobic exercise did not change the walking speed in subacute and chronic stroke.[46] However, this latter review included both trials that implemented HIIT and high intensity continuous training. Recent evidence suggests that AT significantly improves walking speed after stroke.[18,66]

Strengths and limitations

The present study is the first to assess the feasibility of an intensive aerobic interval training program in the first month after stroke using a recumbent bike and, to our knowledge, the first in sub-Saharan Africa. The results of this study could encourage stroke rehabilitation professionals to incorporate intensive aerobic interval training into their routine practice. However, this study has some potential limitations. First, the small sample size and lack of a control group make it difficult to draw clear conclusions on the added value of the HIIT program on physical functions soon after stroke. Although, this limitation does not significantly limit the feasibility of such an intervention early after stroke. Second, analysis of long-term follow-up data to determine whether the benefits observed in physical functions were maintained after the end of the program is also necessary.

5. Conclusion

This study showed that performing high-intensity aerobic interval training, with intervals at 70-80% of peak work rate is feasible and safe for patients with mild to moderate impairments during the first month after stroke. Patients perceive this program as very credible and meets their high expectations towards recovery on admission. In addition, combined HIIT with conventional physiotherapy showed significant improvements in physical functions. Future research should focus on the effectiveness of HIIT in the early post-stroke period with a significant number of participants and a control group.

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