

Research article

Acute Physiological and Perceptual Responses to Whole-Body High-Intensity Interval Training Compared with Equipment-Based Interval and Continuous Training

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Abstract

Low-volume, time-efficient high-intensity interval training (HIIT), which involves whole-body (WB) callisthenics exercises, has gained worldwide popularity in recent years. However, the physiological and perceptual impact of WB-HIIT in comparison to specialised, equipment-based training is relatively less studied. This study compared the acute physiological and perceptual responses to a single session of WB-HIIT, ergometer-based HIIT (ERG-HIIT) and conventional moderate-intensity continuous training (MICT). Fourteen physically inactive adults (age: 28.4 ± 6.5 years, VO_{2peak} : 31.0 ± 6.2 mL · kg⁻¹ · min⁻¹) underwent three main trials (WB-HIIT: 12 x 30-s high-intensity callisthenics workout; ERG: HIIT: 12 x 30-s high-intensity cycling bouts; MICT: 30-min cycling at 50% peak power output) in a randomized cross-over order 3 - 7 days apart. The mean session heart rate (HR) and perceived exertion were comparable across all three protocols ($p > 0.05$). WB-HIIT attained a similar peak HR (87.4 ± 9.4 %HR_{max}) as that of ERG-HIIT (83.0 ± 8.6 %HR_{max}), and significantly greater than that of MICT (78.7 ± 5.5 %HR_{max}, $p = 0.001$). However, WB-HIIT induced significantly higher blood lactate levels (7.2 ± 1.8 mmol/L) compared to both ERG-HIIT (5.1 ± 1.3 mmol/L, $p < 0.05$) and MICT (3.1 ± 1.5 mmol/L, $p < 0.001$). The participants reported higher self-efficacy and greater enjoyment with WB-HIIT compared to MICT ($p < 0.05$). The mean HR and perceived exertion responses to WB-HIIT are comparable to those of equipment-based HIIT and MICT; however, WB-HIIT results in greater metabolic strain than both other modalities. Despite this, the overall perceptual responses to WB-HIIT are positive, suggesting that it could be a viable exercise alternative, especially for individuals with limited exercise time and restricted access to facilities and equipment.

Key words: HIIT, bodyweight training, callisthenics, fitness, public health.

Introduction

The current physical activity (PA) guidelines typically recommend a minimum of 150 minutes of moderate-intensity PA, 75 minutes of vigorous-intensity PA, or an equivalent combination of both per week, in addition to performing whole-body muscle strengthening exercise no less than twice per week (WHO, 2010; ACSM, 2021). Unfortunately, with the well-evidenced benefits of PA and hazards of physical inactivity, compliance with these guidelines

worldwide remains low (WHO, 2016). The most common perceived barrier to PA participation is the lack of time (Stutts, 2002), while accessibility to equipment and facilities and the financial costs of exercise were also reported as typical reasons (Trost et al., 2002; Choi et al., 2017). High-intensity interval training (HIIT) involves short bursts of high-intensity exercise interspersed with short periods of recovery (MacInnis and Gibala, 2017). As a time-efficient exercise mode that often requires less than 30 minutes, HIIT has recently gained widespread popularity among the general population and has been ranked among the top 10 in the American College of Sports Medicine (ACSM) Worldwide Survey of Fitness Trends since 2013 (Thompson, 2022). HIIT typically allows participants to accumulate a longer duration of high-intensity workout by incorporating short breaks, which would otherwise be unsustainable in constant load exercise due to increasing acidosis (MacInnis and Gibala, 2017). Previous studies reported that HIIT utilising specialised equipment (e.g., running treadmills and cycle ergometers) elicited similar or superior training effects when compared to moderate-intensity continuous training (MICT), including cardiorespiratory fitness, body composition and insulin sensitivity improvement (Sawyer et al., 2016; Poon et al., 2021; Poon et al., 2020; Batacan et al., 2017). However, running- or cycling-based HIIT may be constrained by the accessibility of facilities and equipment. Recommendations have been made to promote exercises that are more easily accessible, time-efficient and sustainable in real-world settings, in order to address the common barriers to exercise among the general population (Gray et al., 2016).

In particular, one form of workout that may offer these benefits is whole-body callisthenics training, also commonly known as bodyweight training. Ranking 3rd in the ACSM Worldwide Survey of Fitness Trends for 2023, this type of training is a combination of multiplane bodyweight and neuromotor movements with bodyweight as the primary resistance (Thompson, 2022). The training requires minimal equipment and space, making it an inexpensive and functional way to exercise. When whole-body callisthenics training was conducted in a HIIT format (i.e. whole-body HIIT [WB-HIIT]), it was reported to induce a number of physiological benefits, including a decrease in

body fat, an increase in excess post-exercise oxygen consumption (EPOC), maximum oxygen uptake, and muscular fitness (Klika and Jordan, 2013). However, relatively little is known about the acute effects of WB-HIIT compared with traditional laboratory-based exercise protocols with specialised equipment, despite its current overwhelming popularity worldwide. The efficacy of WB-HIIT should be recognized only when more scientific evidence from well-controlled studies is available.

To the best of our knowledge, no studies have simultaneously compared the acute physiological responses of WB-HIIT to the traditional forms of HIIT and MICT. Given the widespread claim from the fitness industry that WB-HIIT could be an alternative to traditional forms of HIIT and MICT, a direct comparison of the three regimens and knowledge of their corresponding acute responses would help inform the development of effective exercise programs for fitness and health professionals. WB-HIIT or similar kinds of whole-body circuit training would be worth introducing to the general public if they can elicit similar responses to traditional exercise with a relatively low time commitment. Furthermore, previous studies of WB-HIIT often recruited active individuals (Bellissimo et al., 2022; Gist et al., 2014), while responses to the physically inactive population have been less explored. Such a cohort should not be overlooked, since such an easily assessable and time-efficient workout may allow these less-motivated individuals, a priority target of public health promotion, to perform PA regularly which helps ease the global health problem.

Apart from physiological benefits, the perceptual responses to exercise play a key role in adherence and long-term sustainability of exercise programs. According to the classic Dual-Mode Theory, interoceptive cues (e.g. perceived exertion) and cognitive cues (e.g. self-efficacy and enjoyment) can jointly influence affective responses to exercise (Jung et al., 2014). The balance between these two determinants shifts as a function of exercise intensity. Vigorous exercises such as HIIT have been thought to induce greater feelings of displeasure and psychological distress (Blanchard et al., 2001), which in turn, should reduce exercise participation and adherence. However, recent systematic evidence suggests that HIIT may indeed induce similar or even more positive perceptual responses than MICT, despite its more aversive nature (Oliveira et al., 2018; Niven et al., 2021). It would be intriguing to explore how the perceptual responses to WB-HIIT, which are currently underexplored in literature, may interrelate with the cardiometabolic responses.

Therefore, this study aimed to examine the acute physiological and perceptual responses to a single session of low-volume WB-HIIT, ergometer-based HIIT (ERG-HIIT), and MICT in physically inactive adults. We hypothesised that the cardiometabolic strain elicited by a single session of WB-HIIT would be greater than that elicited by MICT, and comparable to that elicited by ERG-HIIT. It was also hypothesised that WB-HIIT would elicit a more positive perceptual responses than MICT but similar to ERG-HIIT.

Methods

Participants

Fourteen physically inactive adults (7 males and 7 females) were recruited for this study (Table 1). Participants were considered physically inactive if they reported less than 150 minutes of moderate or 75 minutes of vigorous PA per week, as assessed using the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). They were not diagnosed with a history of chronic diseases (e.g. hypertension, heart disease, and diabetes), joint ailments, or pregnancy. All participants reported having no prior experience with any kind of regular exercise training. The Physical Activity Readiness Questionnaire (PAR-Q) and informed consent forms were obtained before participation. The minimum sample size of 12 individuals was determined using a *priori* analysis. Based on previous data from our laboratory (Poon et al., 2018), an effect size of $f=0.5$ for the primary physiological outcome (i.e. heart rate [HR] response) was anticipated across trials, with $\alpha=0.05$ and $\beta=0.20$ (G*Power version 3.0.10). This study was approved by the ethical committee of The Chinese University of Hong Kong.

Table 1. Participant characteristics (mean \pm SD).

Parameters	Male (n = 7)	Female (n = 7)	Total (n = 14)
Age (years)	30.7 \pm 7.5	26.1 \pm 4.8	28.4 \pm 6.5
Height (cm)	172.5 \pm 6.3	162.9 \pm 4.8	167.7 \pm 7.3
Body mass (kg)	64.3 \pm 7.9	54.7 \pm 8.5	59.5 \pm 9.3
BMI (kg·m ⁻²)	21.5 \pm 1.5	20.6 \pm 2.9	21.1 \pm 2.3
Body fat (%)	17.4 \pm 2.0	27.2 \pm 7.2	22.3 \pm 2.3
VO _{2peak} (mL·kg ⁻¹ ·min ⁻¹)	34.3 \pm 4.7	27.9 \pm 6.4	31.0 \pm 6.2
PPO (W)	220.7 \pm 35.6	163.0 \pm 23.7	191.8 \pm 41.7
HR _{max} (bpm)	181.0 \pm 15.4	179.0 \pm 12.5	180.0 \pm 10.0
HR at VT1 (%HR _{max})	73.9 \pm 5.3	70.8 \pm 5.0	72.4 \pm 5.3
HR at VT2 (%HR _{max})	83.3 \pm 6.3	82.3 \pm 6.0	82.8 \pm 6.4

BMI, body mass index; PA, physical activity; VO_{2peak}, peak oxygen uptake; PPO, peak power output; HR_{max}, maximum heart rate; VT1, first ventilatory threshold; VT2, second ventilatory threshold.

Study design

This study used a randomised within-subject crossover design (Figure 1). Participants were asked to come to the laboratory on four separate occasions: a preliminary test (peak power output [PPO] and peak oxygen uptake [VO_{2peak}] test) and three exercise trials in randomised and counterbalanced order: 1) WB-HIIT, 2) ERG-HIIT, and 3) MICT. The randomisation of interventions was conducted using an online randomisation tool. (<https://www.random.org/lists/>). Of note, the current research design aimed to enhance the external validity of the study by comparing the three exercise protocols under realistic conditions. It was adapted from previous studies (Poon et al., 2018; Jung et al., 2014; Thum et al., 2017; Poon et al., 2020) to reflect on the relative low-volume and time-efficient nature of HIIT as compared to the traditional high-volume and long-duration nature of MICT, providing greater real-life implications.

HR, blood lactate (BLa), and rating of perceived exertion (RPE) were measured during exercise. Perceptual

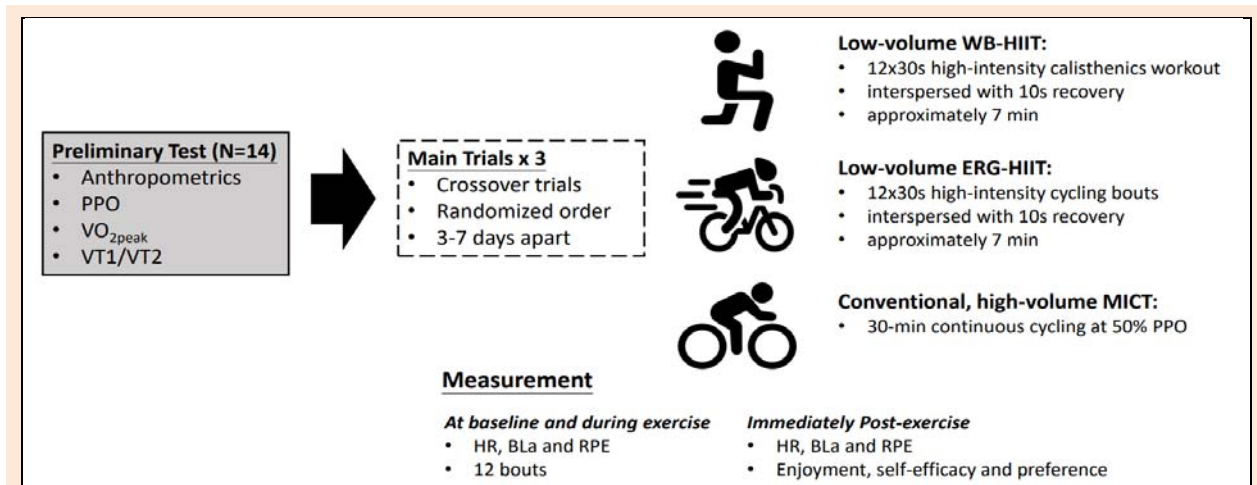


Figure 1. Schematic diagram of the study design. BLA, blood lactate; ERG-HIIT, ergometer-based high-intensity interval training; HR, heart rate; MICT, moderate-intensity continuous training; PPO, peak power output; RPE, rating of perceived exertion; VO_{2peak} , Peak oxygen uptake; VT1, First ventilatory threshold; VT2, Secondary ventilatory threshold; WB-HIIT, whole-body high-intensity interval training

questionnaires measuring enjoyment and self-efficacy were distributed after each trial. To eliminate potential carryover effects, a 3- to 7-day washout period was used between each trial. Participants arrived at the laboratory same time of the day (between 8:00 to 11:00 a.m.) each time to eliminate any circadian effects. Participants were instructed to avoid strenuous exercise, caffeine, and alcohol 24 h before all tests and trials, as well as to fast 3 h before the trials. They were also asked to report their past 24 h food intake after completion of the first trial and then consume the same food the day before all subsequent trials.

Preliminary test

During the first laboratory visit, participants' height was measured using a stadiometer (Seca, Leicester). Body mass, body mass index (BMI), and body fat percentage were determined using a body composition analyser (MC-780MA, Tanita, Japan). Participants were then asked to perform incremental exercise on a testing ergometer (LC7, Monark Exercise AB, Sweden) to measure PPO and VO_{2peak} , based on a protocol reported previously (Lee et al., 2021). The exercise began with a 5-minute warm-up at 50W followed by $20W \cdot min^{-1}$ increases in work rate until volitional exhaustion was attained (pedal cadence <50 revolutions per minute). Participants were encouraged to give maximal effort during the test. PPO was determined using the formula below:

$$PPO = W_{completed} + (t/60 \times 20)$$

where $W_{completed}$ is the power output for the last full workload completed, t is the time in seconds for which the final uncompleted workload was sustained. Pulmonary gas exchange data were 15-second time-averaged, and VO_{2peak} was identified as the mean of the highest 30 seconds. The criteria for verifying maximal exertion were as follows (Edvardsen et al., 2014): a respiratory exchange ratio > 1.10, failure of HR to increase with an increase in workload, and a post-exercise blood lactate levels ≥ 8.0 mmol/L. All participants had to meet at least two of these criteria. VO_{2peak} was measured using a telemetric gas analysis system (MAX-IIa Metabolic System; AEI Technologies, Inc.,

USA), which was calibrated before the start of the exercise. Additionally, HR at the first (VT1) and secondary ventilatory thresholds (VT2) of participants were determined as previously described (Binder et al., 2008). These threshold data were used to evaluate the intensities of the subsequent three exercise trials.

Main trials

The participants were asked to perform WB-HIIT, ERG-HIIT, and MICT in three main trials, and the exercise order was randomly assigned. All exercise protocols were preceded with a 5-minute warm-up at 20% PPO and finished with a 3-minute cool-down at 15% PPO on an ergometer. Pedal cadence was maintained at 70 revolutions per minute during exercise, warm-up, and cool-down.

Whole-body High-intensity Interval Training

A popular WB-HIIT protocol named "7-Minute Workout" was adopted (Klika and Jordan, 2013). This protocol involves a combination of high-intensity aerobic and resistance exercises with a brief rest time. It consists of 12 bodyweight exercises and takes approximately 7 minutes. The twelve 30-second exercises were performed in the following order: (1) jumping jacks, (2) wall sit, (3) push-ups, (4) abdominal crunches, (5) step-ups on the chair, (6) squats, (7) triceps dips on chair, (8) planks, (9) high knees, (10) lunges, (11) push-ups with rotation, and (12) side planks (15 seconds for each side). Each bout was followed by 10 seconds of passive recovery. Participants were instructed to perform as many repetitions as possible during the 30-second exercise and quickly change their body position to prepare for the next bout during the 10-second recovery. A standard chair with 18-inch seat height was used for the exercises (i.e., step-ups and triceps dips) across all participants.

Ergometer-based High-intensity Interval Training

The interval duration and pattern of this ERG-HIIT protocol were matched to WB-HIIT, which involved 7 minutes of work. Twelve 30-second cycling bouts at 70% PPO, separated by a 10-second active recovery at 20% PPO were performed. Of note, this protocol was adopted from a pre-

vious study (Riegler et al., 2017) and considered from a safety perspective. It has been demonstrated to elicit approximately 80 - 90% HR_{max} and was regarded as the highest intensity tolerable by physically inactive individuals with very brief recovery periods (Riegler et al., 2017).

Moderate-intensity Continuous Training

Participants performed a 30-minute continuous cycling at 50% PPO in the MICT trial. This protocol and intensity were chosen as they correspond to a typical MICT commonly used in the literature (MacInnis and Gibala, 2017).

Measurements

HR was measured continuously via telemetry (Sport Tester PE 4000, Polar Electro, Finland) during exercise (12 bouts in total). RPE and BL_a were measured before and immediately after the exercise. The revised category-ratio scale (0 to 10) (Borg, 1998) was used to assess participants' overall perceived exertion, in which a score of 0 represents "nothing at all" and a score of 10 represents "maximal exertion". For BL_a, a small amount of blood sample (20µL) was acquired using a portable analyser (Lactate Plus, Nova Biomedical, Waltham, MA, USA) and fingerstick lancets. This device demonstrated a strong reliability ($r = 0.99$) with no proportional bias, and small fixed bias (<0.2 mmol/L) in comparison with a reference analyser (YSI 2300) (Hart et al., 2013). Following the cool-down of the exercise, participants were asked to complete the Physical Activity Enjoyment Scale (PACES) (Kendzierski and DeCarlo, 1991) and a task-specific Self-efficacy Questionnaire (McAuley et al., 1999). PACES is an 18-item, 7-point bipolar scale that indicates participants' enjoyment level towards the exercise task, and a higher score (out of 126) indicates a higher enjoyment level. The 5-item Self-Efficacy Questionnaire was designed to determine participants' confidence in repeating each exercise trial. The 5 items included the stem, "How confident are you that you can...perform (one to five) bouts of exercise per week for the next 4 weeks that is just like the one you completed today?" Responses were scored as a percentage of 0% (not at all) to 100% (extremely confident) in 10% increments. At the end of the final exercise trial, participants were asked to indicate their exercise preferences among WB-HIIT, ERG-HIIT, and MICT.

Statistical analyses

Descriptive statistics (mean \pm SD) were calculated across

different trials. Data were analysed using IBM SPSS Statistics 26.0. Two-way repeated measures ANOVA was used to compare changes in the BL_a, and RPE of the exercises across time and trials, whereas one-way repeated-measures ANOVA was used to compare the results of mean HR, peak HR, enjoyment and self-efficacy between the three trials. If a significant F ratio was obtained, Bonferroni's post-hoc test was conducted for pairwise comparisons. Cohen's d was used to indicate the magnitude of the difference between trials upon pairwise comparisons, where appropriate (Cohen, 1992). Scores of 0.2, 0.5, and >0.8 , were considered small, moderate, and large effect sizes, respectively. Statistical significance was set at $p < 0.05$.

Results

All the participants completed three designated exercise trials. No adverse events were reported. The results of physiological and perceptual responses to the three protocols are summarised in Table 2.

Physiological responses

Change in heart rate

There was no significant difference in mean HR response (expressed in either bpm or %HR_{max}) among three protocols (Table 2 and Figure 2, $p > 0.05$). The peak HR of WB-HIIT was comparable to that of ERG-HIIT, and significantly greater than that of MICT (Table 2 and Figure 2, $p < 0.05$). During WB-HIIT, HR increased in bout 1 (jumping jack, 136.5 ± 17.9 bpm) but started to decrease afterward until bout 4 (crunches, 123.5 ± 13.6 bpm). HR then gradually increased in bouts 5 (step-ups, 136.2 ± 16.0 bpm) and 6 (squats, 144.3 ± 12.1 bpm) but slightly decreased in the next two bouts. In response to bout 9 (high knees, 155.5 ± 18.4 bpm), HR further increased until bout 11 (push-ups with rotation, 158.1 ± 15.8 bpm) and decreased in the last bout (side plank, 146.4 ± 16.6 bpm). During ERG-HIIT and MICT, HR steadily increased throughout the exercise from bout 1 (ERG-HIIT: 123.7 ± 11.5 ; MICT: 126.7 ± 13.6 bpm) to bout 12 (HIIT: 148.5 ± 17.0 ; MICT: 140.3 ± 15.2 bpm).

Change in blood lactate

There were significant main effects of time ($p < 0.001$), trials ($p < 0.001$), and significant time \times trial interactions ($p < 0.001$) on BL_a concentration (Table 2 and Figure 3a).

Table 2. Summary of physiological and perceptual responses to the three protocols.

	WB-HIIT	ERG-HIIT	MICT	ANOVA (p -value)		
				Trial	Time	Trial \times Time
Mean session HR (bpm)	140.0 \pm 14.3	141.3 \pm 14.9	135.5 \pm 12.8	0.213	NA	NA
Mean session HR (%HR _{max})	78.5 \pm 8.7	79.1 \pm 8.0	75.8 \pm 5.4	0.189	NA	NA
Peak session HR (bpm)	158.1 \pm 15.8 ^b	148.7 \pm 16.2	141.4 \pm 15.8	0.023	NA	NA
Peak session HR (%HR _{max})	87.4 \pm 9.4 ^b	83.0 \pm 8.6	78.7 \pm 5.5	0.020	NA	NA
Baseline lactate (mmol/L)	1.3 \pm 0.4	1.3 \pm 0.7	1.0 \pm 0.3	< 0.001	< 0.001	< 0.001
End lactate (mmol/L)	7.2 \pm 1.8 ^{ab}	5.1 \pm 1.3 ^c	3.1 \pm 1.5			
Baseline RPE (out of 10)	0.1 \pm 0.3	0.1 \pm 0.1	0.1 \pm 0.1	0.78	< 0.001	0.206
End RPE (out of 10)	5.9 \pm 0.3	4.7 \pm 0.1	4.8 \pm 0.1			
PACES score (out of 126)	97.6 \pm 13.7 ^b	97.9 \pm 16.8 ^c	82.4 \pm 20.3	< 0.01	NA	NA
Self-efficacy score (out of 100)	68.4 \pm 23.1 ^{ab}	60.6 \pm 26.3	53.3 \pm 27.6	0.020	NA	NA

^a $p < 0.05$ between WB-HIIT and ERG-HIIT; ^b $p < 0.05$ between WB-HIIT and MICT; ^c $p < 0.05$ between ERG-HIIT and MICT. HR, heart rate; PACES, Physical Activity Enjoyment Scale; RPE, rating of perceived exertion.

WB-HIIT (7.2 ± 1.8 mmol/L) induced significantly higher BLa concentrations at the end of the exercises than ERG-HIIT (5.1 ± 1.3 mmol/L, $p = 0.008$, $d = 1.3$) and MICT (3.1 ± 1.5 mmol/L, $p < 0.001$, $d = 2.5$) did. ERG-HIIT elicited a significantly higher concentration than MICT ($p = 0.001$, $d = 1.5$).

Change in Rating of Perceived Exertion

There was a significant effect of time on the RPE ($p < 0.001$). However, no significant main effect of the trial ($p = 0.78$) or interaction in RPE ($p = 0.206$) was observed (Table 2 and Figure 3b).

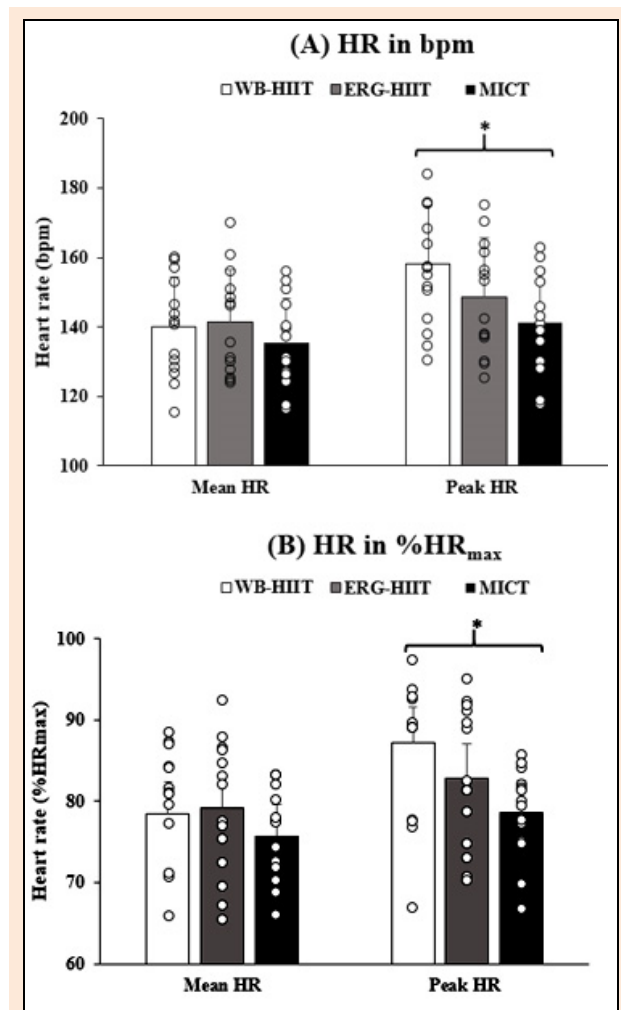


Figure 2. Differences in mean and peak HR responses to WB-HIIT, ERG-HIIT, and MICT (mean \pm SD) (a) in bpm (b) in %HR_{max}. * $p < 0.05$ between WB-HIIT and MICT.

Perceptual responses

Enjoyment

There was a significant effect of trials on the enjoyment level ($p < 0.01$). PACES scores of WB-HIIT (97.6 ± 13.7) and ERG-HIIT (97.9 ± 16.8) was significantly higher than that of MICT (82.4 ± 20.3 , both $p < 0.05$, $d = 0.8$). No significant differences were observed between WB-HIIT and ERG-HIIT ($p > 0.05$).

Task specific self-efficacy

There was a significant effect of trials on the self-efficacy

score ($p < 0.05$). The score was significantly higher in WB-HIIT (68.4 ± 23.1) than in the MICT (53.3 ± 27.6 , $p = 0.015$, $d = 0.59$). No significant differences were observed between WB-HIIT and ERG-HIIT (60.6 ± 26.3 , $p = 0.627$) or ERG-HIIT and MICT ($p = 0.465$).

Preference

Fifty percent of participants (7 out of 14) indicated WB-HIIT as their first choice among three protocols, while 36% and 14% selected ERG-HIIT and MICT, respectively.

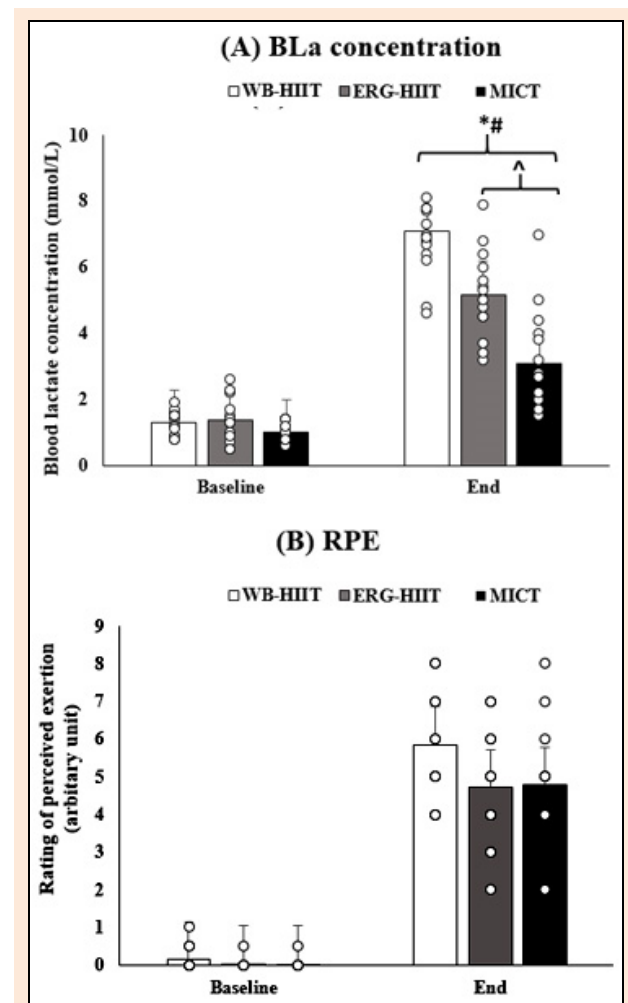


Figure 3. Differences in (a) BLa concentration and (b) RPE responses to WB-HIIT, ERG-HIIT, and MICT (mean \pm SD). * $p < 0.05$ between WB-HIIT and MICT; # $p < 0.05$ between WB-HIIT and ERG-HIIT; ^ $p < 0.05$ between ERG-HIIT and MICT.

Discussion

This study aimed to compare the acute physiological and perceptual responses between the widely promoted, low-volume WB-HIIT and two traditional forms of exercise utilising specialised equipment, ERG-HIIT and MICT. The main finding of the present investigation is that the mean HR and perceived exertion responses to WB-HIIT are comparable to those of equipment-based HIIT and MICT; however, it is associated with greater metabolic strain than both other modalities. Despite its relatively strenuous nature, perceptual responses to WB-HIIT appear to be more

positive than those to ERG-HIIT and MICT.

The mean and peak HR attained during WB-HIIT was 78.5 ± 8.7 and 87.4 ± 9.4 %HR_{max} respectively, which fell within the category of vigorous intensity (77 - 95%HR_{max}) as per the current PA guidelines (ACSM, 2021). In particular, the peak HR exceeded the estimated HR at VT2 (82.8 ± 6.4 %HR_{max}) obtained from the spirometric data during the participants' incremental exercise, indicating that WB-HIIT could be considered a form of vigorous exercise comparable to ERG-HIIT (Gist et al., 2014; Riegler et al., 2017). Of note, WB-HIIT revealed a distinct pattern of HR responses from that of ERG-HIIT. While HR increased steadily throughout the consecutive bouts in ERG-HIIT, it was observed that HR during WB-HIIT increased sharply when dynamic lower-body exercises (e.g. jumping jack, step-up onto the chair, squat, high knee, and lunges) were performed but remained steady or slightly decreased in exercises with smaller muscle groups (e.g. triceps dip and crunch) or with an isometric nature (e.g. plank and wall-sit). From a practical perspective, this implies that fitness professionals can manipulate the overall intensity of WB-HIIT based on the nature of calisthenics exercises involved, assisting in the design and implementation of individualised exercise programs (i.e. incorporating more dynamic, multi-joint movements would increase the overall intensity of WB-HIIT and vice versa).

Among the three exercise protocols, WB-HIIT induced significantly higher BLA concentrations than ERG-HIIT and MICT. Compared to ERG-HIIT and MICT which mainly engaged the lower limb muscles, the exercises included in WB-HIIT were performed from the upper to the lower body. Activation of more skeletal muscles may thus increase the overall exercise intensity and place greater reliance on non-oxidative metabolism within the skeletal muscles, leading to greater BLA accumulation (Riegler et al., 2017). Moreover, the current PA guidelines (ACSM, 2021; WHO, 2010) recommend performing resistance exercises regularly for muscular health. As suggested by the "strength–endurance continuum", the WB-HIIT protocol is comparable to low-weight, high-repetition resistance exercise which could improve muscular endurance (Campos et al., 2002). Therefore, WB-HIIT may have the additional benefit of improving muscular fitness and musculoskeletal health when compared to ERG-HIIT and MICT.

To date, a handful of experimental studies have investigated the long-term effects of low-volume WB-HIIT on the human physiological system and reported a number of benefits similar to traditional HIIT with specialised equipment, such as improvements in cardiorespiratory fitness, muscular endurance, and body composition (McRae et al., 2012). It has been proposed that physiological adaptation is caused by the accumulation of "microadaptations" after each exercise session (Fluck, 2006; Riegler et al., 2017). Therefore, WB-HIIT may result in long-term responses similar to traditional HIIT if similar cardiometabolic stimuli are elicited (Riegler et al., 2017). Among the available literature, Riegler et al. compared acute responses between WB-HIIT (utilizing the same "7-Minute Workout" protocol as the present study) and ERG-HIIT in fourteen habitually active individuals (Riegler et al., 2017). In line with our study, their results suggested that WB-HIIT was

characterized by vigorous bursts approaching 90% HR_{max} and led to significant higher BLA accumulation (towards the end of exercise) than ERG-HIIT, despite yielding slightly lower peak VO₂ and mean HR. Another study by Bellissimo et al. recently compared the acute responses between WB-HIIT (utilizing "all-out" calisthenic exercises) and treadmill running HIIT in twelve physically active adults (Bellissimo et al., 2022). Their findings also showed similarities with our present study in that WB-HIIT can elicit vigorous cardiorespiratory, BLA, and RPE responses. While these two previous studies were both conducted in a relatively active cohort, our study further demonstrated that comparable responses between WB-HIIT and equipment-based HIIT could be observed in physically inactive individuals, who are priority targets for public health promotion. Moreover, our findings extend the existing body of literature by simultaneously demonstrating a greater cardiometabolic stimulus of WB-HIIT compared to conventional, high-volume MICT, which is commonly recommended for sedentary populations (WHO, 2010; ACSM, 2021). Taken together, our findings reveal that the acute cardiometabolic strains elicited by WB-HIIT are comparable to equipment-based HIIT and greater than MICT, which may confer a range of physiological benefits in the long term, without the need for specialised equipment.

Another novelty of the current study is the comparison of perceptual responses among the three exercise protocols, which can have significant behavioural implications. Both HIIT protocols in the present study showed a significantly higher enjoyment response than MICT. Our finding aligns with prior research which generally revealed that HIIT elicits higher perceived enjoyment than MICT (Bartlett et al., 2011; Thum et al., 2017; Jung et al., 2014), suggesting potentially better long-term exercise adherence. The more positive enjoyment response to the HIIT protocols can be due to the intermittent nature (i.e., "on-off" nature) of high-intensity intervals, which may help keep participants engaged and motivated (Bartlett et al., 2011). Conversely, MICT involves more repetitive movements, which can be perceived as monotonous and less enjoyable, particularly for physically inactive young adults (Poon et al., 2018). Furthermore, WB-HIIT demonstrated the greatest self-efficacy among the three protocols, and was significantly higher than that of MICT. Defined as the conviction and belief that one can successfully perform a given task, self-efficacy has been demonstrated to be an important predictor of the adoption and maintenance of exercise behaviour, especially in less physically active adults (Fletcher and Banasik, 2001). It has been suggested that the completion of high-intensity intervals may lead to successive positive accomplishments and multiple successful experiences that increase exercise self-efficacy (Jung et al., 2014). Moreover, the overall positive perceptual responses to WB-HIIT can be attributed to its apparent time efficiency as well as its greater variety in exercise selection within a single circuit (or session) and minimal equipment required compared to specialised, equipment-based HIIT and MICT. Based on the association between self-efficacy and exercise adherence, WB-HIIT may be a more feasible exercise option than ERG-HIIT or MICT, especially for the physically inactive group investigated in the current study.

While our present findings generally support the application of WB-HIIT as an exercise alternative in the physically inactive cohort, some limitations and practical constraints should be considered cautiously, regardless of its proposed benefits. Firstly, we were not able to conduct maximal effort tests to quantify the relative intensity for all twelve different exercises included in the WB-HIIT protocol. Thus, it was rather difficult to control intensity in the WB-HIIT which may increase the risk of over- or underuse in our untrained participants. This practical concern suggests that a more regulated exercise on an ergometer may be more suitable for individuals who are less fit, particularly when applied in clinical settings. In addition, the 10-second recovery period varied slightly between the trials, being passive in the WB-HIIT and active in ERG-HIIT, and this discrepancy might potentially impact lactate oxidation during recovery (Buchheit and Laursen, 2013). Moreover, the involvement of vigorous, high-impact exercises (e.g. high knee, jumping jacks, step-ups on the chair) may cause significant contraction-induced muscle damage (Lieber and Friden, 1999), or even safety concerns for physically inactive individuals, especially those who are overweight and obese (Bliddal et al., 2014). Therefore, the injury rate of WB-HIIT should be further explored to promote a safe, time-efficient, and easily accessible exercise alternative to the general public. Furthermore, it is noteworthy that while our study was intentionally designed to reflect real-world exercise practice (i.e. individuals typically perform WB-HIIT/ equipment-based HIIT with low volume and MICE with higher volume and longer duration), the absolute workload difference between the three protocols may limit their direct comparison (Hofmann and Tschakert, 2010; Tschakert et al., 2015). However, we believe that this more practically-based study design can address some of the limitations and research gaps that cannot be solved by the traditional approach. Moreover, our post hoc analysis showed that mean session HR and perceived exertion were comparable across all three protocols. Nonetheless, future studies are encouraged to investigate the independent moderating effect of each specific training variable (e.g. different duration, relative intensities, work-recovery ratios, and modalities) to provide a more comprehensive understanding of the effects of WB-HIIT in comparison to other exercise strategies. Last but not least, it is common for individuals to incorporate mixed training protocols that alternates between HIIT and other exercise regimens in real-world practice, rather than adhering to a “one-size fits all” principle. Further studies could be conducted to determine whether incorporating WB-HIIT in a combined training approach is more effective than performing WB-HIIT alone.

Conclusion

The results of this study reveal that the mean HR and perceived exertion responses to WB-HIIT are comparable to those of equipment-based HIIT and MICT; however, WB-HIIT results in greater metabolic strain than both other modalities. Despite this, the overall perceptual responses to WB-HIIT are positive, suggesting that it could be a viable exercise alternative, especially for individuals with limited

exercise time and restricted access to facilities and equipment. Future research is warranted regarding its long-term efficacy and safety compared to other exercise modes.

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Key points

- The mean heart rate and perceived exertion to a single session of whole-body high-intensity interval training (WB-HIIT) are comparable to those of conventional ergometer-based high-intensity interval training and moderate-intensity continuous training.
- However, WB-HIIT results in greater metabolic strain than both other modalities.
- The overall perceptual responses to WB-HIIT are positive, suggesting that it could be a viable exercise alternative, especially for individuals with limited exercise time and restricted access to facilities and equipment.

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