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Body composition, cardiorespiratory fitness, and neuromuscular adaptations induced by a home-based whole-body high intensity interval training

Corentin Scoubeau [a], Julie Carpentier [b], Stéphane Baudry [c], Vitalie Faoro [a], Malgorzata Klass [b, c, *]

[a] Cardio-Pulmonary Exercise Laboratory, Faculty of Motor Sciences, Université libre de Bruxelles, Belgium
[b] Research Unit in Biometry and Exercise Nutrition, Faculty of Motor Sciences, Université libre de Bruxelles, Belgium
[c] Laboratory of Applied Biology and Research Unit in Applied Neurophysiology, Faculty of Motor Sciences, ULB Neuroscience Institute, Université libre de Bruxelles, Belgium

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ABSTRACT

Background/objective: Bodyweight exercises performed at home could be a complementary approach to improve health-related fitness in people having little spare time and during stay-at-home periods. This study then investigated body composition, cardiorespiratory fitness, and neuromuscular adaptations to a home-based, video-directed, whole-body high-intensity interval training (WB-HIIT).

Methods: Fourteen subjects participated to an 8-week WB-HIIT (6 females, 23 ± 1 years) and fourteen were included in a non-exercise control group (CTL; 6 females, 24 ± 4 years). All took part to pre- and post-intervention assessments of body composition, peak oxygen uptake (VO_2peak) and first ventilatory threshold (VT1; index of aerobic capacity), dynamic (leg press 3-repetition maximum) and isometric strength (knee extensors maximal isometric contractions with assessment of voluntary activation), and muscle endurance during an isometric submaximal contraction maintained till exhaustion. WB-HIIT consisted in 30-s all-out whole-body exercises interspaced with 30 s of active recovery. Training sessions were performed at home by means of videos with demonstration of exercises. Heart rate was monitored during sessions.

Results: WB-HIIT increased VO_2peak (5%), VT1 (20%), leg lean mass (3%), dynamic (13%) and isometric strength (6%), and muscle endurance (28%; $p < 0.05$), while they did not improve in CTL. VO_2peak increase was correlated ($r = 0.56$; $p < 0.05$) with the time spent above 80% of maximal heart rate during training sessions. Isometric strength increase was correlated with change in voluntary activation ($r = 0.74$; $p < 0.01$).

Conclusion: The home-based WB-HIIT induced concomitant cardiorespiratory fitness and neuromuscular improvements. The predominant effect was observed for aerobic capacity and muscle endurance which could improve exercise tolerance and reduce fatigability.

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1. Introduction

It is commonly admitted that regular physical activity is beneficial for health.[1] The World Health Organization recommends practicing 150–300 min of moderate to vigorous intensity aerobic activity per week, and muscle-strengthening activities on 2 or more days a week.[2] Unfortunately, a large part of the population does not meet these recommendations.[3] Among barriers to physical activity, lack of time or nearby facilities, cost, and weather conditions are the most mentioned.[4] More recently, the COVID-19 pandemic restrictions exacerbated sedentary behavior and limited participation in outdoor activities.[5–7] In this context, a call was made to develop exercise interventions easily achievable at home, and building both endurance and strength.[7–9] These type of interventions could be

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[*] Corresponding author. Research Unit in Biometry and Exercise Nutrition, Faculty of Motor Sciences, Université libre de Bruxelles, Belgium.
E-mail address: Malgorzata.Klass@ulb.be (M. Klass).

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also useful to overcome the above-mentioned barriers to physical activity. Several previous studies proposed home-based interventions, but mostly in a context of telerehabilitation for patients with chronical diseases[10–17] or elderly subjects.[18–20] In these studies, exercise type and intensity were adapted for the targeted population, and interventions either focused on a single component (e.g., endurance, strength, or balance)[10,12,18] or aimed to improve both strength and endurance.[11,15,16,20] The latter approach involves several aerobic and strength training sessions per week[16] or longer sessions combining both types of training.[11,15,20] Protocols and results of these interventions may thus not be transferable to healthy adults having many constraints on their time.

Among interventions that can be proposed at home, whole-body high intensity interval training (WB-HIIT) could be particularly relevant for promoting physical activity in healthy adults. WB-HIIT is a form of high intensity interval training (HIIT) considered as a time-efficient modality to improve cardiorespiratory fitness.[21] While traditional HIIT involves running, biking, or rowing exercises, WB-HIIT uses multi-joint exercises performed with the resistance of bodyweight. It has then the potential to target simultaneously the cardiorespiratory and neuromuscular systems.[22] Therefore, WB-HIIT could be an attractive option for healthy adults having little spare time. Another advantage of WB-HIIT is that it can be easily provided by means of videos. Videos are more engaging than text-based content and can be easily shared through social media platforms.[23,24]

Benefits of WB-HIIT on health-related fitness were exposed in a recent meta-analysis highlighting improvements of cardiorespiratory fitness, body composition, and muscle strength and endurance.[25] However, only a few studies used home-based interventions.[26–30] In addition, none investigated the neuromuscular function (i.e., maximal strength and associated volitional drive, and endurance time during a submaximal contraction). There is then no evidence that home-based WB-HIIT could simultaneously improve body composition, cardiorespiratory fitness, and neuromuscular function.

Accordingly, the aim of this study is to assess the effectiveness of an 8-week home-based WB-HIIT to improve the above-mentioned components, and to better understand the determinants of training-induced adaptations. We hypothesize that the home-based WB-HIIT will simultaneously improve body composition, cardiorespiratory fitness, and neuromuscular function.

2. Materials and methods

2.1. Participants and study design

This study used a randomized controlled design with 2 groups (WB-HIIT and control) and repeated measures on time (baseline to post-intervention). To be included, subjects had to be aged between 18 and 50 years, and to be below the World Health Organization's recommendations in terms of physical activity participation.[2] Exclusion criteria were: (1) being involved in a structured endurance or strength training within the last 6 months, (2) having a condition limiting participation to maximal physical tests and training (e.g., cancer, cardiovascular or lung disease, neuromuscular or musculoskeletal disorder). All volunteers received written information regarding the protocol and had the opportunity to ask questions before signing the written consent. The experimental protocol was approved by the Ethical Committee of the Erasmus Hospital in Brussels (reference: B4062019942321).

The study took place during the COVID-19 pandemic period (between February and November 2021). Participants were randomly assigned either to the WB-HIIT or to the control group (CTL). Participants assigned to the WB-HIIT participated to an 8-week intervention performed at home while maintaining their dietary habits. CTL participants were asked to keep their physical and dietary habits as stable as possible.

Participants first completed the global physical activity questionnaire to ensure they met inclusion criteria regarding physical activity participation. Before and after the intervention, evaluation sessions were carried out in our laboratory on 3 different days interspaced by 48 h. During the first session, participants underwent body composition assessment and a maximal cardiopulmonary exercise test to assess cardiorespiratory fitness. Neuromuscular assessment was performed during 2 separate sessions to avoid fatigue accumulation. Firstly, knee extensors maximal isometric torque, voluntary activation, and endurance time during a submaximal isometric contraction were assessed. Then, during the last session, lower limb dynamic strength was assessed by measuring the 3-repetition maximum (3-RM) on a leg press.

Neither participants nor investigators were blinded regarding group allocation during the intervention and assessments. However, each assessment protocol was standardized. Indeed, the investigator followed written instructions indicating the sequence of steps and encouragement during tests. Then, group allocation and timing of evaluation sessions were concealed, and data were independently analyzed by two investigators.

Based on the size effect reported in a recent meta-analysis on the effects of WB-HIIT on health-related fitness,[25] sample size calculation was performed using G*Power (University of Düsseldorf, Germany). The following parameters were used: 2 groups, 2 measurements, effect size of 0.38, two-tailed alpha error of 0.05, power (1-ß error) of 0.90, nonsphericity correction of 1, and correlation between repeated measures of 0.5. The calculation suggested a minimal total sample of 22 participants to identify statistically meaningful effects.

The participant flowchart is presented in Fig. 1. Thirty healthy adults were initially recruited. One of them declined to participate, and one did not meet inclusion criteria. The remaining subjects were assigned to the WB-HIIT group or the CTL group. To balance the number of males and females between both groups, participants were first stratified by sex (two strata: male and female). Within each stratum, block randomization was then applied to assign an equal number of subjects to the WB-HIIT and control group. Three subjects from the WB-HIIT group discontinued the exercise intervention after a few sessions, two due to a health problem, unrelated to the study, and the third one due to a lack of time. To replace these early dropouts, three additional subjects were included. Ultimately, 28 subjects took part to pre-intervention sessions and finished the WB-HIIT ($n = 14$) or CTL intervention ($n = 14$). Their anthropometric characteristics and physical activity participation at inclusion are presented in Table 1.

Out of these 28 subjects, MVC torque, voluntary activation, and endurance time of one female subject from the CTL group were excluded from the analysis since she did not take part to the post-intervention session dedicated to these measurements. The VO_2peak value of one female subject from the WB-HIIT group was also excluded due to a technical problem with the breath-by-breath analyzer during the post-intervention session.

2.2. Body composition assessment

Total and segmental body composition was assessed after overnight fast using dual energy X-ray absorptiometry[31] (DXA; Lunar Prodigy, GE Healthcare, Madison, WI, USA), and was analyzed using the enCORE software (version 15.0).

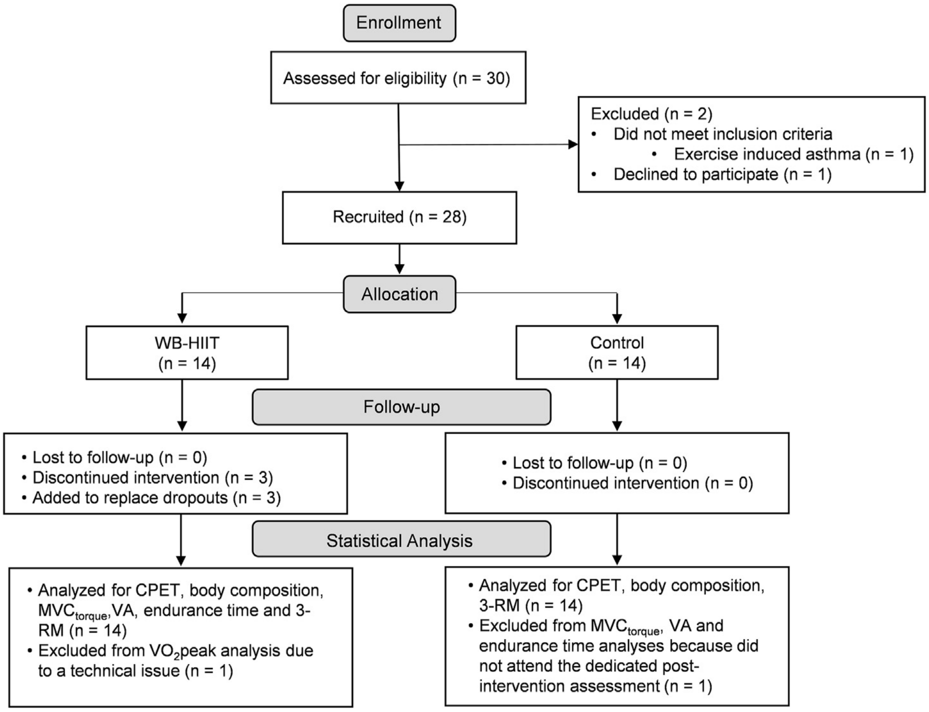

Fig. 1. Participant flowchart. CPET, cardiopulmonary exercise test; MVC, maximum voluntary contraction; 3-RM, 3-repetition maximum; VA, voluntary activation; WB-HIIT, whole-body high intensity interval training.

Table 1
Baseline characteristics and recreational physical activity of the subjects at inclusion.

Group	Ratio F/M	Age (years)	Height (cm)	Body mass (kg)	BMI (kg/m^2)	Intense PA (min/wk)	Moderate PA (min/wk)
WB-HIIT	6/8	23.1 ± 1.3	170.6 ± 11.5	63.8 ± 11.2	21.7 ± 3.3	8 ± 20	19 ± 25
CTL	6/8	24.0 ± 3.9	170.8 ± 8.2	70.3 ± 18.1	23.8 ± 5.3	6 ± 17	41 ± 43

BMI, body mass index. CTL, control group. F, female. M, male. PA, physical activity. WB-HIIT, whole-body high-intensity interval training group. wk, week.

2.3. Cardiorespiratory fitness assessment

Cardiorespiratory fitness was assessed during an incremental cardiopulmonary exercise test performed on a stationary bike (Ergoselect 100, Ergoline GmbH, Germany) following standard recommendations.[32] Oxygen uptake (VO_2), carbon dioxide production (VCO_2) and ventilation (VE) were collected breath-by-breath through a tightly fitted facial mask. Expiratory gas was analyzed using a cardiopulmonary exercise system (Ergocard, Medisoft, Belgium) calibrated with room and standardized gas. The testing protocol started with a 3-min warm up at 20 W for women and 30 W for men. Workload was increased by 15 W/min for women and 20 W/min for men until exhaustion. The test was considered as maximal when at least two of the following criteria were met: (1) an increase in VO_2 of less than 100 ml/min with a further increase in workload (plateau of VO_2), (2) a respiratory exchange ratio greater than 1.15, (3) inability to maintain a pedaling frequency of 50 rpm, (4) or achievement of age-predicted maximal heart rate (HR). Since a plateau of VO_2 was not observable in most of participants, VO_2peak measured during the last minute of the test was reported. HR was monitored with a 12-lead EKG. The cardiopulmonary exercise test allowed the determination of VO_2peak, maximal HR (HRmax), maximal power output (Wmax), and first ventilatory threshold (VT1) determined using the V-slope and the ventilatory equivalents method.[32,33] VT1 is considered as the intensity associated with the onset of anaerobic metabolism during exercise, and is an objective index of aerobic exercise capacity in patients and healthy subjects.[34] VO_2peak and VO_2 at VT1 were reported in absolute values (L/min) and in relative values (per kilogram of total lean mass).[35]

2.4. Neuromuscular assessments

2.4.1. Maximal isometric torque and muscle endurance

For the recording of neuromuscular parameters, subjects were sitting on an adjustable chair with a back rest. Their hip and knee angles were set at 100°. The right leg was attached to a force transducer, connected to the front of the chair using a velcro strap placed ~2 cm above the lateral malleolus (detailed description previously published).[36] To limit trunk displacement during contractions, the subject was secured to the chair by a harness.

The isometric torque produced by the knee extensor muscles was measured using a force transducer (linear range, 0–2500 N; U2000 load cell, Maywood Instruments Ltd, Basingstoke, UK). Torque was calculated by multiplying the force measured with the transducer by the lever arm (i.e., distance between the center of the transducer and the axis of rotation of the knee joint). Electromyographic activities (EMG) were recorded from the rectus femoris, vastus medialis, vastus lateralis and biceps femoris muscles by means of 2 self-adhesive electrodes (3 M, Red Dot™) placed over each muscle belly. The reference electrodes were located over the lateral condyle of the tibia. Before placing the electrodes, skin was shaved when necessary and cleaned with a solution of alcohol, ether, and acetone to reduce electrode-skin impedance. To ensure similar recording conditions during the pre- and post-intervention sessions, location of the EMG electrodes on each muscle was recorded during the first session to place them in the same position during the post-intervention session. EMG signals were amplified (x 1000) and filtered (10 Hz - 1 kHz) by a custom-made differential amplifier.

Torque and EMG signals were acquired on a computer at a sampling rate of 2 kHz with a data-acquisition system (Model MP 150, Biopac Systems, Santa Barbara, CA, USA) and analyzed off-line with associated AcqKnowledge 4.1 software.

To assess voluntary activation and muscle contractile properties, electrical stimulation was delivered to the femoral nerve by a constant current stimulator (pulse duration 200-μs; DS7AH Digitimer, Welwyn Garden City, UK) through self-adhesive electrodes (3 M, Red Dot™). The electrodes were placed over the nerve in the femoral triangle (cathode) and between the greater trochanter and the iliac crest (anode).[36] The precise location of the cathode was determined at rest by using weak electrical stimulation. The stimulus intensity was then increased to induce a maximal twitch and EMG response in the vastus medialis. The intensity of the stimulation was set 30% above to ensure a maximal activation of the muscles at rest and during contraction.

The testing took place as follows. At their arrival to the laboratory, EMG and stimulating electrodes were placed and subjects were installed in the experimental chair. After a warm-up (3 × 5 contractions at respectively 25, 50, and 75% of the maximum estimated by the subject), two familiarization 3-s isometric maximal voluntary contractions (MVC) were performed with a 3-min rest interval. The experimental recordings then started with three 3-s MVC interspersed by 3-min rest intervals. Voluntary activation was tested using the interpolated twitch technique with paired supramaximal electrical stimuli delivered at 10-ms interval during the MVC plateau and at rest, immediately after the end of the MVC.[36] Finally, after a 10-min rest period, muscle endurance (i.e., the ability to maintain a specific percentage of MVC for a prolonged period of time)[37] was assessed during a 30% MVC contraction maintained till exhaustion.[38] Visual feedback of the actual and target torque was displayed on a monitor located in front of the subject.

MVC torque and associated average value of the rectified EMG (aEMG) of the vastus medialis, vastus lateralis, rectus femoris, and biceps femoris were measured for a 500-ms period during the plateau of the three MVC. Values measured during the two trials that yielded the largest MVC torque were averaged and used to calculate 30% MVC. The peak torque of the twitch evoked at rest by the paired stimulation was also measured. Voluntary activation level was calculated according to the following equation: (1 − superimposed torque/torque of the twitch induced at rest in response to paired stimulation) x 100.[39,40] The superimposed torque was calculated as the difference between the superimposed peak torque and the MVC torque. To quantify muscle endurance, we measured the endurance time from the beginning of the contraction till the moment subjects were 10% below the target torque, for at least 5 s, despite verbal encouragement.

2.4.2. Dynamic lower limb strength

Dynamic lower limb strength was assessed through the 3-RM performed on an inclined leg press (Hammer strength, IL, USA). Evaluation began with a 5-min warm-up on a stationary bike. Subjects were then asked to perform a specific warm-up consisting in 10 repetitions on the unloaded press (53 kg). Position of the feet on the press plate was recorded to reproduce the positioning during the post-intervention test. The load was then progressively increased, and participants were asked to achieve 4 repetitions with each load. A repetition was valid if it was performed over the full range of motion (90° flexion to full extension). A 5-min resting period was given between tries and the 3-RM was considered reached if participants achieved 3 repetitions and failed the 4th.

2.5. WB-HIIT intervention

The 8-week home WB-HIIT content was conceptualized by the investigators and was provided to the subjects by means of 4 videos created by the “French and Fit” company (Brussels, Belgium). In the videos, instructions of each exercise were given by a professional coach, and the exercise was simultaneously demonstrated by a subject. Training sessions started with a 3-min warm-up and ended with a few minutes of stretching. The conditioning phase consisted in sets of 4 × 30-s all-out whole-body exercises (Table 2) interspaced with 30 s of active recovery (jogging on the spot). Participants performed 3 sets during week 1 and 2, and 4 sets during week 3–8. Subjects were instructed to perform as many repetitions as possible during the exercise phase, and the coach gave verbal incentives. For the sake of progression, each exercise presented on the videos was proposed with a basic and harder variant (Table 2). Participants were asked to perform 3 sessions a week, on non-consecutive days, and to use each video for 2 weeks in a row. They were advised to perform the basic variant during the first week and the harder one during the second week. In addition, the technical and muscular difficulty of the exercises increased from video 1 to 4.

HR was recorded during the sessions using a Polar H9 heart rate sensor (Polar, Finland) connected to the “Polar Beat” app on a smartphone or tablet. It was then exported to the Polar Flow app which displays mean and peak HR of each session, and the time spent in different intensity zones, expressed in percentage of the estimated HRmax based on age (220 − age): light (60–70%), moderate (70–80%), high 80–90%, and maximal (>90% HRmax) intensity.

Participants could contact the investigators in case of difficulty with the execution of exercises or with the recording of HR. They were also contacted regularly to ensure that the training is going well. At the end of the study, the WB-HIIT videos were made available to all participants.

2.6. Statistical analysis

Normality of the data was controlled using a Shapiro–Wilk normality test. To test if both groups presented similar characteristics at baseline (i.e., pre-intervention), a between-group comparison was conducted using either an independent *t*-test or a Mann-Whitney *U* test depending on the normality of distribution. A two-factor ANOVA (time [baseline vs. post-intervention] × group [WB-HIIT vs. CTL]) with repeated measures on time was used to analyze training induced changes when the distribution was normal. When a significant time × group interaction was found, the Bonferroni's post hoc test was used to compare baseline to post-intervention values in each group. When data did not present normal distribution (i.e., percentage of body fat, trunk fat mass, relative VO_2peak, and endurance time), a Wilcoxon test was used to analyze within-group changes.

Since the initial voluntary activation level of our subjects was high (>90% in most of the subjects), and therefore less likely to improve, we correlated the individual initial voluntary activation level with the percentage of change in voluntary activation. To identify the main mechanism contributing to a potential improvement in MVC torque,[41] the percentage of change in torque was correlated with the changes in voluntary activation and leg lean mass. As VO_2peak changes could be influenced by the cardiorespiratory strain imposed during training sessions,[42,43] the

Table 2
Description of the whole-body high intensity intervention exercises.

Weeks	Sets number	Training program	
		Basic variant	Harder variant
1–2	3	1. Jumping jacks 2. Squats with lateral raise 3. Twist jumps 4. Mountain climbers	1. Low jacks 2. Jump squats with lateral raise 3. Twist jumps at faster pace 4. Mountain climbers at faster pace
3–4	4	1. Low jacks 2. Plank jacks 3. Lunges with knee lift 4. Knee raises with trunk rotation	1. Squat jumps 2. Plank jacks at faster pace 3. Back lunge jumps 4. Squats to knee raise with trunk with rotation
5–6	4	1. Reverse lunges with knee raise and trunk rotation 2. Squat jumps 3. Front lunges 4. Low impact burpees	1. Reverse lunges on tiptoe with knee raise and trunk rotation 2. Squat jumps at faster pace 3. Jumping front lunges 4. Burpees without vertical jump
7–8	4	1. Back lunge jumps 2. Side stepping with knee raise 3. Jumping lunges 4. Mountain climbers followed by squat jump	1. Deep back lunge jumps 2. Side stepping with knee raise at faster pace 3. Deep jumping lunges 4. Cross body mountain climbers followed by squat jump

correlation between the time spent above 80% HRmax and the percentage of change in VO_2peak was assessed. Pearson (r_p) or Spearman (r_s) correlation coefficients were calculated depending on data distribution.

Statistical analyses were performed using Jamovi software (version 2.2.5). Data are presented as mean ± SD when normally distributed or as median [25th, 75th percentiles] for data not normally distributed. The statistical level of significance was set at 0.05.

3. Results

3.1. Intensity of WB-HIIT sessions

Except 2 subjects who missed 2 training sessions, all the participants completed the 24 sessions of the exercise intervention. Maximal and mean HR recorded during the WB-HIIT sessions were respectively 88 ± 5 and 74 ± 5 %HRmax. The time spent within the four intensity zones is presented in Table 3.

3.2. Body composition

Data and statistical analysis of body composition at baseline and post-intervention are presented in Table 4. There was no significant difference at baseline between groups for total and segmental fat and lean mass (all baseline p-values >0.05). The statistical analysis did not reveal any significant change in total and segmental fat mass, percentage of body fat, and in total, arm and trunk lean mass (all ANOVA and within group comparisons p-values >0.05). A slight increase was observed for leg lean mass (3%) after WB-HIIT ($p = 0.022$), while it did not change in the CTL group ($p > 0.99$).

Table 3
Time spent in the different intensity zones.

Intensity zone	%HRmax	Time spent (min:sec)	
Light	60–70%	0:57	[0:06, 1:44]
Moderate	70–80%	5:45	[3:25, 7:44]
High	80–90%	5:58	[3:56, 8:13]
Maximal	>90%	0:11	[0:00, 1:06]

Time spent in each zone is presented as median [25th, 75th percentile]. %HRmax, percentage of maximum heart rate (220 − age).

3.3. Cardiorespiratory fitness adaptations

Data and statistical analysis of cardiorespiratory fitness at baseline and post-intervention are presented in Table 5. No statistical difference between groups was observed at baseline (all baseline p-values >0.05). The statistical analysis revealed a significant increase for the absolute and relative VO_2peak ($p = 0.031$ and 0.027, respectively), VT1 ($p = 0.002$), and Wmax ($p = 0.008$) after WB-HIIT. No change was found in the CTL group (all within group comparisons p-values >0.05). The individual and mean percentages of change in VO_2peak, Wmax, and VT1 after WB-HITT and in the CTL group are illustrated in Fig. 2A.

There was a significant correlation between the time spent above 80% HRmax and the percentage of change in absolute ($r_s = 0.56$; $p = 0.049$) and relative VO_2peak ($r_s = 0.56$; $p = 0.048$).

3.4. Neuromuscular adaptations

Data and statistical analysis of neuromuscular parameters at baseline and post-intervention are presented in Table 6. There was no significant difference between groups at baseline for any of the parameters (all baseline p-values >0.05). The 3-RM and MVC torque increased after WB-HIIT ($p < 0.001$ and 0.033, respectively), while MVC torque decreased in the CTL group ($p = 0.033$). Voluntary activation, aEMG during the MVC, and twitch torque at rest did not change significantly in any of the groups (all ANOVA and within group comparisons p-values >0.05). Endurance time measured during the 30% MVC contraction increased after WB-HIIT ($p = 0.026$) but did not change in the CTL group ($p = 0.553$). The individual and mean percentages of change in 3-RM, MVC torque, and endurance time after WB-HITT and in the CTL group are illustrated in Fig. 2B.

Although there was no significant change in the mean voluntary activation after the WB-HIIT, our results indicated a negative correlation ($r_p = -0.80$; $p < 0.001$) between the subjects' initial voluntary activation level and the percentage of change in voluntary activation, and a positive correlation ($r_p = 0.55$; $p = 0.040$) between the percentage of change in voluntary activation and in MVC torque. In contrast, the correlation between the percentage of change in leg lean mass and MVC torque was not significant ($p = 0.418$).

Table 4
Baseline to post-intervention comparison of body composition.

Parameter	Baseline	Post	Baseline WB-HIIT vs. CTL	ANOVA Time × group
			p-value	**p-value**
Body fat percentage				
WB-HIIT	31.6 [23.3, 34.7]	31.5 [21.8, 34.3]	0.541	N/A
CTL	31.3 [28.2, 37.4]	31.4 [29.0, 36.9]		
Total fat mass (kg)				
WB-HIIT	18.4 ± 5.8	18.4 ± 5.9	0.195	0.556
CTL	22.0 ± 8.3	22.3 ± 8.5		
Total lean mass (kg)				
WB-HIIT	42.4 ± 7.8	43.0 ± 7.7	0.420	0.261
CTL	45.5 ± 11.5	45.5 ± 11.8		
Leg fat mass (kg)				
WB-HIIT	8.1 ± 2.3	8.0 ± 2.3	0.341	0.329
CTL	9.0 ± 2.9	9.2 ± 3.1		
Leg lean mass (kg)				
WB-HIIT	16.6 ± 2.7	17.1 ± 2.6*	0.290	**0.014**
CTL	18.0 ± 4.1	18.0 ± 4.0		
Arm fat mass (kg)				
WB-HIIT	1.9 ± 0.6	1.9 ± 0.5	0.233	0.272
CTL	2.2 ± 0.7	2.3 ± 0.8		
Arm lean mass (kg)				
WB-HIIT	4.5 ± 1.4	4.5 ± 1.3	0.361	0.922
CTL	5.1 ± 2.0	5.1 ± 2.1		
Trunk fat mass (kg)				
WB-HIIT	7.7 [5.0, 9.4]	7.4 [4.8, 9.4]	0.401	N/A
CTL	9.2 [5.1, 11.3]	8.9 [5.6, 11.7]		
Trunk lean mass (kg)				
WB-HIIT	18.4 ± 3.5	18.4 ± 3.5	0.594	0.943
CTL	19.3 ± 5.3	19.3 ± 5.5		

*Data presented as mean ± standard deviation or median [25th, 75th percentile]. *Significantly different from baseline value within this group ($p < 0.05$). CTL, control group. N/A, not applicable. WB-HIIT, whole-body high intensity interval training group.*

Table 5
Baseline to post-intervention comparison of the cardiopulmonary exercise test parameters.

Parameter	Baseline	Post	Baseline WB-HIIT vs. CTL	ANOVA Time × group
			p-value	p-value
VO_2peak (L/min)				
WB-HIIT	2.35 ± 0.51	2.46 ± 0.50*	0.694	**0.012**
CTL	2.25 ± 0.69	2.20 ± 0.71		
Relative VO_2peak (ml/kg$_{LM}$/min)				
WB-HIIT	50.3 [49.3, 59.3]	56.2 [50.9, 62.7]*	0.155	N/A
CTL	47.8 [41.4, 57.7]	48.3 [42.5, 53.6]		
Wmax (Watts)				
WB-HIIT	193 ± 43	204 ± 40*	0.743	**0.004**
CTL	186 ± 54	182 ± 57		
HRmax (bpm)				
WB-HIIT	193 ± 8	191 ± 8	0.131	0.835
CTL	187 ± 11	186 ± 9		
VO_2 at VT1 (L/min)				
WB-HIIT	1.31 ± 0.33	1.56 ± 0.36*	0.922	**0.012**
CTL	1.30 ± 0.56	1.29 ± 0.46		
Relative VO_2 at VT1 (ml/kg$_{LM}$/min)				
WB-HIIT	30.9 ± 4.5	36.3 ± 5.3*	0.362	**0.006**
CTL	28.5 ± 8.5	28.4 ± 6.9		

*Data presented as mean ± standard deviation or median [25th, 75th percentile]. *Significantly different from baseline value within this group ($p < 0.05$). HRmax, maximal heart rate. LM, total lean mass. N/A, not applicable. Relative VO_2peak, peak oxygen uptake per kilogram of total lean mass. Relative VO_2 at VT1, oxygen uptake at VT1 per kilogram of lean mass. VO_2peak, peak oxygen uptake measured during the last minute of the test. VT1, first ventilatory threshold. Wmax, maximal power output.*

4. Discussion

The present study assessed the adaptations of body composition, cardiorespiratory fitness, and neuromuscular function induced by a WB-HIIT performed at home. Our results show that the home-based WB-HIIT improved cardiorespiratory fitness (VO_2peak and VT1), muscle strength and endurance, and slightly increased leg lean mass. The predominant effect was observed for aerobic capacity (VT1) and muscle endurance. A dose-response relationship was observed between the time spent at high intensity during training sessions and VO_2peak change. Changes in voluntary activation and MVC torque were correlated, suggesting that strength improvement after WB-HIIT was mainly related to an increased volitional drive.

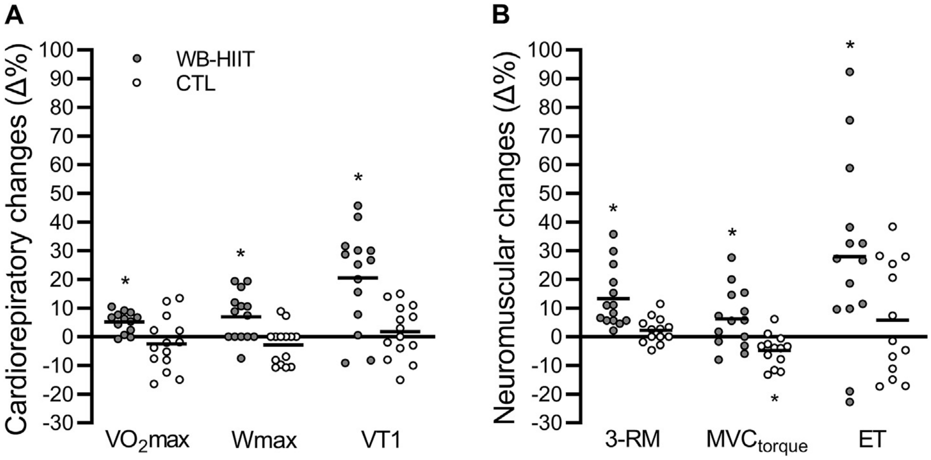

Fig. 2. Individual and mean changes in cardiorespiratory fitness (A) and neuromuscular function (B) expressed in percentage of baseline values. The horizontal lines represent the mean changes. *Significant change from baseline value within this group ($p < 0.05$). CTL, control group. ET, endurance time during submaximal contraction. MVC, maximum voluntary contraction. 3-RM, 3-repetition maximum. VO_2peak, peak oxygen uptake. VT1, first ventilatory threshold. WB-HIIT, whole-body high-intensity interval training. Wmax, maximal power output.

Table 6
Baseline to post-intervention comparison of neuromuscular parameters.

Parameter	Baseline	Post	Baseline WB-HIIT vs. CTL	ANOVA Time × group
			p-value	p-value
3-RM (kg)				
WB-HIIT	247 ± 62	278 ± 71*	0.102	**0.009**
CTL	312 ± 127	321 ± 135		
MVC torque (N.m)				
WB-HIIT	159 ± 50	168 ± 54*	0.451	**0.001**
CTL	177 ± 70	167 ± 65*		
Voluntary activation (%)				
WB-HIIT	93 ± 6	95 ± 4	0.343	0.264
CTL	91 ± 8	91 ± 7		
Twitch torque (N.m)				
WB-HIIT	60 ± 16	62 ± 14	0.125	0.127
CTL	71 ± 22	71 ± 20		
VL aEMG (μV)				
WB-HIIT	324 ± 131	333 ± 145	0.291	0.342
CTL	381 ± 146	362 ± 155		
VM aEMG (μV)				
WB-HIIT	626 ± 330	618 ± 228	0.219	0.608
CTL	499 ± 153	467 ± 190		
RF aEMG (μV)				
WB-HIIT	376 ± 203	388 ± 160	0.295	0.558
CTL	301 ± 154	292 ± 158		
BF aEMG (μV)				
WB-HIIT	122 ± 71	130 ± 68	0.161	0.089
CTL	91 ± 29	79 ± 21		
Endurance time (s)				
WB-HIIT	133 [114, 181]	187 [131, 252]*	0.730	N/A
CTL	151 [114, 244]	166 [108, 229]		

*Data presented as mean ± standard deviation, or median [25th, 75th percentile], *Significantly different from baseline value within this group ($p < 0.05$). aEMG, average value of the rectified electromyographic activities. BF, biceps femoris. MVC, maximal voluntary contraction. N/A, not applicable. RF, rectus femoris. 3-RM, 3- repetition maximum. VL, vastus lateralis. VM, vastus medialis.*

4.1. Body composition

The absence of change in fat mass is consistent with most of previous studies that proposed both supervised[44–47] and home-based WB-HIIT in normoweight subjects.[27,29] In contrast, fat loss was reported after supervised and home-based WB-HIIT in overweight participants.[26,48,49] Total lean mass was not significantly changed after WB-HIIT. This result is in agreement with previous studies showing mitigated effects of supervised[44,46,48–50] and home-based[26,27,30] WB-HIIT on total lean mass.

To our best knowledge, no other study assessed segmental body composition changes after supervised or home-based WB-HIIT. The small improvement observed in leg lean mass, but not in trunk and arm lean mass, could be explained by the type of exercises. Indeed, our training protocol was composed of bodyweight exercises mostly involving lower limbs. Muscle hypertrophy is considered to be initiated by high mechanical loading of the muscle.[51,52] However, recent literature suggested that hypertrophy may also be triggered by rapid and repeated transitions from eccentric to concentric portion of the movement (i.e., stretch-shortening cycles),[53,54] and accumulation of fatigue related metabolites (i.e., metabolic stress).[51,52,54–56] Although the training load is moderate (i.e., bodyweight), WB-HIIT involves fast concentric and eccentric contractions of the lower limbs. This, combined to the previously reported high blood lactate concentration attained during WB-HIIT,[56] could have triggered the slight increase in leg lean mass.[56,57]

4.2. Cardiorespiratory fitness adaptations

The VO_2peak improvement after WB-HIIT is consistent with previous studies using either supervised[44,45,48–50,58–60] or home-based WB-HIIT.[26,28,30] The slight increase observed for VO_2peak (5%) could be due to the short time spent at high intensity (see Table 3). This is in line with a recent study showing that oxygen consumption is lower during WB-HIIT compared to a running HIIT with a similar exercise to rest ratio.[56] This hypothesis is also supported by the dose-response relationship between the time spent at high intensity and VO_2peak improvements shown by present and previous studies.[61] WB-HIIT is indeed characterized by a greater complexity and muscle strain, due to the use of bodyweight multi-joint exercises, which may limit execution pace and HR increase as compared to unimodal HIIT.[56]

The large improvement of VT1 (20%) indicates a stronger effect of WB-HIIT on the submaximal aerobic exercise capacity than on VO_2peak. VT1 corresponds to an intensity at which ventilation starts to increase faster than VO_2[62] to compensate the metabolic acidosis by the bicarbonate buffering system.[32,63] A low VT1 is associated with a premature onset of exercise-related hyperventilation, a higher perceived exertion during exercise,[64] and an earlier exercise cessation.[65] VT1 is therefore considered as a better indicator of aerobic endurance capacity (i.e., maximal time spent at a submaximal intensity) than VO_2peak.[34,65,66] To our knowledge, only two studies assessed VT1 change after home-based WB-HIIT, and reported a significant increase.[28,30] Given the low impact of WB-HIIT on VO_2peak, VT1 enhancement is most probably due to an improvement in muscle aerobic capacity, rather than a greater ability of the cardiorespiratory system to deliver oxygen to the muscles.[66]

While the exact muscular mechanisms induced by WB-HIIT still need to be investigated, they could be partly common to those reported after HIIT: increased muscle mitochondrial content and function,[67] reduced glycogen utilization, and greater muscle buffering capacity.[68,69] This would delay lactate production and accumulation, and slow down the development of peripheral fatigue.[70] This is supported by a recent study showing that home-based WB-HIIT induces similar improvements in muscle capillarization and mitochondrial density than home-based moderate intensity continuous training or supervised HIIT.[26]

4.3. Neuromuscular adaptations

4.3.1. Muscle strength and voluntary activation

The strength increase observed after the home-based WB-HIIT is in line with previous studies that investigated effect of WB-HIIT on dynamic muscle strength (i.e., 1-repetition maximum).[49,59,71] However, to our best knowledge, our study is the first to investigate changes in MVC torque and voluntary activation of the knee extensors after WB-HIIT. This approach allows a further discussion of the mechanisms involved in strength improvement.

The MVC torque increased after WB-HIIT, whereas it was reduced in the CTL group. The decrease in the CTL group is most probably due to a slightly lower involvement in physical activity and/or active displacements during the COVID-19 pandemic,[72] despite the instruction to keep physical activity habits stable. The associated EMG activities of the agonist (vastus medialis, vastus lateralis and rectus femoris) and antagonist (biceps femoris) muscles were not modified in any group. This is in line with the absence of change in the mean voluntary activation. However, the initial level of voluntary activation was already high in our subjects (93 and 91% in the WB-HIIT and CTL group, respectively). This may have reduced the extent of possible improvement and the sensitivity of the interpolated twitch technique to detect changes.[39,40] For this reason, we correlated the individual initial activation level with the change in voluntary activation after WB-HIIT, and observed a negative relation. This observation suggests that WB-HIIT has a greater potential to improve voluntary activation in subjects with a lower initial activation level. Also, as MVC torque increase was positively correlated with voluntary activation change, but not with leg lean mass change, neural mechanisms should have mainly contributed to the strength improvement. This is also supported by the absence of change in twitch torque which is an indicator of muscle contractile properties.[73]

Resistance training, using high loads, is considered as the best strategy to improve muscle strength.[55] However, improvements in MVC torque have also been reported following biking or running HIIT,[38,74–76] although not systematically.[77–79] The strength increase observed after HIIT is thought to be related to the high intensity of the working phases and short recovery times favoring type 2 fibers recruitment.[80,81] WB-HIIT involves repeated multi-joint explosive exercises performed with bodyweight as resistance. Performance of this type of exercises requires an intense volitional drive that could result in an even larger type 2 fibers recruitment and strengthening effect. The greater improvements of the 3-RM, proportionally to MVC torque (see Fig. 2B), is most probably linked to the specific motor skills and segmental coordination trained during whole-body exercises. It would then further improve performance at multi-joint dynamic strength tests than at monoarticular isometric tests.

4.3.2. Muscle endurance

In present study, WB-HIIT induced a larger improvement in muscle endurance than strength. Previous studies have reported that WB-HIIT increases muscle endurance, quantified by plank endurance time or by the number of repetitions performed during a certain time or till exhaustion.[27,44,46,47,50,58,59,82,83] However, the similarity of the tests with the exercises performed during training makes it difficult to distinguish improvement due to acquisition of specific motor skills from real gain in muscle endurance. The novel finding of an increased endurance time during a submaximal isometric contraction, untrained during the exercise intervention, supports WB-HIIT effectiveness to enhance muscle endurance.

Intramuscular mechanisms regulating aerobic capacity (evoked above to explain VT1 improvement), but also a greater resistance to inhibitory actions of III/IV muscle afferents[84] and tolerance to muscular disconfort,[85,86] could contribute to increase muscle endurance after WB-HIIT.

4.4. Limitations and perspectives

There are some limitations to this study. First, our sample was composed of mostly inactive but healthy young adults. Therefore, present results are not transferable to inactive populations with limitations (e.g., subjects with physical limitations/risk factors due to their age, overweight, or medical condition). Enlarge the investigated populations will provide additional information on the feasibility and efficacy of WB-HIIT in various populations with a low participation in physical activities. Further studies should also compare different types of protocols (e.g., different session duration, type of exercises, work/rest ratio, etc.) to optimize WB-HIIT programming.

Second, although the intensity of sessions was monitored through recording of HR, the “all-out” execution of exercises could not be controlled during sessions. This aspect is however intrinsically linked to the training modality and the home-based design of the intervention. To our knowledge, only one study monitored intensity through HR during WB-HIIT sessions.[44] Due to the impact of intensity on the induced adaptations, further studies should systematically monitor and report training intensity. This will facilitate results interpretation and between study comparisons.

Finally, the very slight increase in leg lean mass (3%) should be interpreted with caution since it is just above the precision of the Lunar Prodigy DXA (1–2%).[31] But if confirmed, it could represent an interesting complementary approach for subjects with limited time or access to fitness facilities.

4.5. Functional implications

Although a significant effect was observed for VO$_2$peak, muscle strength and leg lean mass, WB-HIIT had a greater effect on submaximal performance (i.e., VT1 and muscle endurance). VT1 and muscle endurance were assessed during different types of effort (i.e., dynamic aerobic exercise vs. submaximal isometric contraction) and therefore depend on partly different mechanisms which need further investigations. However, the concomitant enhancement of these parameters should improve exercise tolerance and facilitate performance of daily life activities. Indeed, most of daily tasks involve repeated submaximal aerobic efforts and sustained muscle contractions.[87,88]

In addition, an advantage of WB-HIIT is the possibility to adapt the type of exercises and execution depending on the primary goal and targeted population. Compared to moderate intensity aerobic training, a recent study also showed greater enjoyment during WB-HIIT sessions[89] and higher motivation to exercise after the intervention.[71]

5. Conclusion

The home-based WB-HIIT is feasible and induces concomitant cardiorespiratory fitness and neuromuscular improvements. A dose-response relationship was observed between the magnitude of VO$_2$peak change and the time spent at high intensity (above 80% of HRmax). Strength improvement was due to a greater volitional drive rather than an increased muscle mass. The predominant effect on submaximal aerobic capacity and muscle endurance should contribute to improve exercise tolerance and reduce fatigue during daily activities.

Author statement

C.Scoubeau, J.Carpentier, V.Faoro, and M.Klass conceived the study design. C.Scoubeau, J.Carpentier, and M.Klass conceived the exercise intervention. C.Scoubeau, J.Carpentier, and M.Klass collected the data. C.Scoubeau, J.Carpentier, V.Faoro, and M.Klass analyzed the data. C.Scoubeau, J.Carpentier, and M.Klass performed the statistical analysis. C.Scoubeau, J.Carpentier, V.Faoro, S.Baudry, and M.Klass drafted and revised the manuscript. All authors gave their consent for the final version of the manuscript.

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Declaration of competing interest

The authors declare no conflict of interest.

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