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Research article

The Effects of a Single Session of High Intensity Functional Training on Energy Expenditure, VO_2, and Blood Lactate

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Abstract

High intensity functional training (HIFT) provides a potential option to meet public exercise recommendations for both cardiorespiratory and strength outcomes in a time efficient manner. To better understand the potential for HIFT as an exercise approach, energy expenditure (EE) and relative intensity need quantifying. In thirteen sedentary men and women with metabolic syndrome (MetS), we used both indirect calorimetry and blood lactate levels to calculate EE of a single session of HIFT. The HIFT session included four, 6-minute sets of consecutive functional exercises. Examples of the exercises involved were squats, deadlifts, suspension rows, suspension chest press, and planks. Intensity is described relative to individual ventilatory thresholds. The total group EE was 270.3 ± 77.3 kcal with approximately 5% attributed anaerobic energy production. VO_2 ranged between 88.8 ± 12.3% and 99 ± 12% of the second ventilatory threshold (VT2), indicating a vigorous effort. After each work interval, peak blood lactate ranged between 7.9 ± 1.9 and 9.3 ± 2.9 mmol, and rate of perceived exertion between 6.9 ± 1.0 and 8.7 ± 0.8 arbitrary units from 1-10. These were achieved in approximately 46 minutes of exercise per participant. In conclusion, HIFT elicits the energy expenditure and effort requisite to result in the adaptive responses to produce the known suite of benefits of exercise for individuals with MetS.

Key words: Acute exercise, ventilatory threshold, metabolic syndrome.

Introduction

Compelling evidence confirms that regular exercise improves health as well as reduces risk of many chronic diseases, and therefore public exercise recommendations are published worldwide (Liguori et al., 2021; Garber et al., 2011; World Health Organization, 2020.). Specifically, individuals with metabolic syndrome (MetS) respond favorably to exercise interventions (Dalleck et al., 2014, 2013). Unfortunately, only 1 in 4 adults meet the publicly communicated recommendations (World Health Organization, n.d.). The common reported barriers include a "lack of time" and "lack of enjoyment" (Costello et al., 2011; Greaney et al., 2009; Grubbs and Carter, 2002; Korkiakangas et al., 2009). High-intensity interval training (HIIT); defined as brief bouts of vigorous aerobic exercise interspersed with brief periods of rest or low-intensity aerobic exercise; has been proposed as a time-efficient option of exercise (Gibala et al., 2012; Gillen and Gibala, 2014). Investigations into a variety of intensity and interval protocols within a range of populations have determined HIIT improves health and fitness as well as reduces disease risk (Gibala and Little, 2020; Gillen and Gibala, 2014). Despite the time-efficiency, effectiveness, and safety of HIIT protocols, there is conjecture that the requisite intensity may compromise adherence and motivation, owing to perceptions of discomfort (Ekkekakis et al., 2011). High-intensity functional training (HIFT) is another time-efficient modality of exercise, differing from HIIT due to its incorporation of resistance exercises in combination with high-intensity aerobic exercise (Feito et al., 2018). Preliminary data on the perceptive responses to HIFT found that subjects reported higher enjoyment, were more likely to continue, and spent significantly less time exercising with HIFT than the publicly recommended modalities (Heinrich et al., 2014). Hence, HIFT might conceivably contribute to health outcomes for individuals with MetS.

To accurately compare HIFT to other exercise interventions, knowing the energy expenditure and relative intensity of a bout aids in understanding the potential adaptations if consistently performed. The combined modality and wide diversity of HIFT designs present a challenge though when comparing effects to uni-modal exercise (Browne et al., 2020; Feito et al., 2018). Even though HIFT bouts always involve high-intensity aerobic, resistance, and functional exercises, the potential prescription parameter combinations are multiple (Browne et al., 2020). In four studies involving varying length and designs of HIFT for both males and females, a session average of 7.5 kcal/min for 45 min (Brisebois et al., 2021), 15.1 kcal/min for 35 min (Browne et al., 2020), 10.8 kcal/min for 44 min (Willis et al., 2019), and 9.7 kcal/min for 15 min (Morris et al., 2019) were reported. Average intensities of ~ 80% of heart-rate maximum (HR_{max}) (Willis et al., 2019), and ~ 92% HR_{max} (Browne et al., 2020) have hitherto been reported. These preliminary studies demonstrate the considerable variability in the energy expenditure and relative intensity of HIFT protocols, due to the multitude of ways this exercise modality can be executed.

Further exploration of additional physiological responses is needed to better understand potential adaptive outcomes from regular HIFT. For instance, the aerobic intensity and resistance exercise of HIFT elicits energy production from not only aerobic sources, but also a significant contribution from anaerobic sources (Balsom et al., 1994; Browne et al., 2020; Tesch et al., 1986; Willis et al., 2019). Indirect calorimetry is commonly used to measure energy expenditure of aerobic exercise, however it has been proposed that this method often understates expenditure for resistance exercise, a primarily anaerobic activity (Scott, 2006). It is suggested that blood lactate collection

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can be used to estimate what indirect calorimetry cannot capture during resistance training, and has been shown to represent a large contribution of energy expenditure (Scott, 2006). Furthermore, the extended metabolic rate during excess post-oxygen consumption (EPOC) represents an essential component of energy expenditure after resistance exercise and therefore should also be measured (Scott, 2011). These methods can be used as a reasonable practice to attenuate expenditure underestimations of HIFT.

The two prior studies identifying the intensity of HIFT (Browne et al., 2020; Willis et al., 2019) used a percent max heart rate (%HR) method (Liguori et al., 2021), which opens the possibility of a wide variation in the individual metabolic responses attributed to physiological change (Mann et al., 2014). Recent investigations have proposed using ventilatory thresholds (VT), based on individual metabolic responses, as measures of exercise intensity, because it reduces this variation and leads to better training responsiveness (Weatherwax et al., 2019; Wolpern et al., 2015). We suggest using this method to identify the intensity of HIFT rather than %HR. Accordingly, the purpose of the current exploration of a single session of HIFT is to 1) measure total energy expenditure using indirect calorimetry as well as blood lactate collection and EPOC methods, and 2) identify the intensity via percentage of the VT's, in a population of sedentary adults with MetS.

Methods

Participants

Thirteen sedentary men and women between the ages of 30-65 yrs; possessing at least 3 cardiometabolic risk factors for MetS (ATP III, 2002) were recruited via local business employee listservs, community flyers, newspaper ads, and word of mouth. Each participant reviewed and signed the informed consent then study inclusion was determined through a Health History Questionnaire, cardiometabolic screening and functional movement assessment. This study was approved by the ethics committee of Auckland University of Technology [21/79] and Human Research Committee of Western Colorado University (WCU) [HRC2020-01-01-R04].

Cardiometabolic & functional movement screening

After completion of informed consent and health history questionnaire, participants were scheduled for two screening appointments at the High Altitude Performance Lab (HAP Lab) at WCU. First, participants visited the HAP Lab after an overnight fast and were measured for blood lipids and glucose, resting blood pressure (BP), resting heart rate (HR), and resting oxygen saturation (SaO_2), as well as stature, weight, abdominal circumference, and sagittal abdominal diameter (SAD) (Liguori et al., 2021; Van Guilder and Kjellsen, 2020). For blood lipids and glucose, 40uL of capillary blood was collected via fingerprick and analyzed for total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), non-HDL-C, triglycerides (TG), and glucose (FBG) with the Cholestech LDX Analyzer (Abbott Diagnostics, Abbott Park, IL). TG/HDL and TC/HDL ratios were calculated. For the second screening appointment, participants arrived at the HAP Lab ready to exercise and were instructed and evaluated on their performance of the following functional movements; hinge, squat, lunge, push, pull, press, plank, and torso rotation. All participants who met the inclusion criteria and demonstrated no major movement issues were included in the study. Participants who met the inclusion criteria and demonstrated minor deviations in movement performance were given daily corrective exercises to perform on their own and evaluated at subsequent training appointments until proper movement was achieved. To minimize the confounding effects of weight loss, participants were counseled to maintain their current habitual diet and physical activity behaviors.

Study design

See Figure 1 for Experimental Design and Figure 2 for Testing Week Timeline. Participants began the study with a graded exercise test (GXT) along with a verification bout on a treadmill to quantify maximal oxygen consumption (VO_{2max}), and the first (VT1) and second (VT2) ventilatory thresholds. Thereafter, a 3-week familiarization period was implemented during which the participants progressed to the target HIFT session. Toward the end of this period, the participants performed a rehearsal HIFT session to familiarize with the testing procedures to come.

Five to seven days following the familiarization period, participants visited the HAP Lab for two consecutive mornings. On day 1, after an overnight fast, baseline measures of resting energy expenditure (REE) were completed. On day 2, after an overnight fast, participants performed the rehearsed HIFT session while VO_2 and HR were continuously collected and lactate and RPE were measured pre-, after each set, and post-session. Immediately following exercise, the participants rested for 30 min while VO_2 was collected to quantify post-exercise oxygen consumption (EPOC).

Procedures

Graded Exercise Test (GXT)

The GXT was performed on a power treadmill (CT850, Spirit Fitness, Jonesboro, AR) in the HAP Lab. Participants were instructed on the CR10 rating of perceived exertion (RPE) (Borg, 2001) and walking protocol. Next, they were outfitted with a HR monitor (Polar F1, Polar USA, Warminster, PA), connected to a metabolic cart (Oxycon Mobile, CareFusion Respiratory Care, Yorba Linda, CA) and positioned on the treadmill. The GXT began with a 5-min warm-up at a self-selected pace, gradually reaching the pace participants maintained throughout the test. A modified Balke & Ware (Balke and Ware, 1959) protocol was used where participants maintained their constant speed while incline was increased by 1% each minute until volitional exhaustion. Breath-by-breath gas exchange and continuous HR data were collected and averaged every 15 sec and RPE was measured in the last 10 sec of each minute. Upon completion, VT1 and VT2 were identified, calculated as the point in which the plotted ventilation rate makes an a-linear increase. Maximal HR and workload were also recorded. Next, participants passively rested for 20 min before performing a verification trial to confirm VO_{2max} (Astorino et al., 2009; Nolan et al., 2014; Weatherwax et al., 2016). For the verification trial, participants walked on the treadmill at 105% of their maximal workload during the GXT (last fully completed stage) until volitional exhaustion again. If the VO_{2max} of the verification bout and GXT were within ±3%, true VO_{2max} was considered achieved (Astorino et al., 2009; Nolan et al., 2014; Weatherwax et al., 2016). If participants were unable to reach VO_{2max}, they were asked to repeat the trial after a 24-96 hr rest.

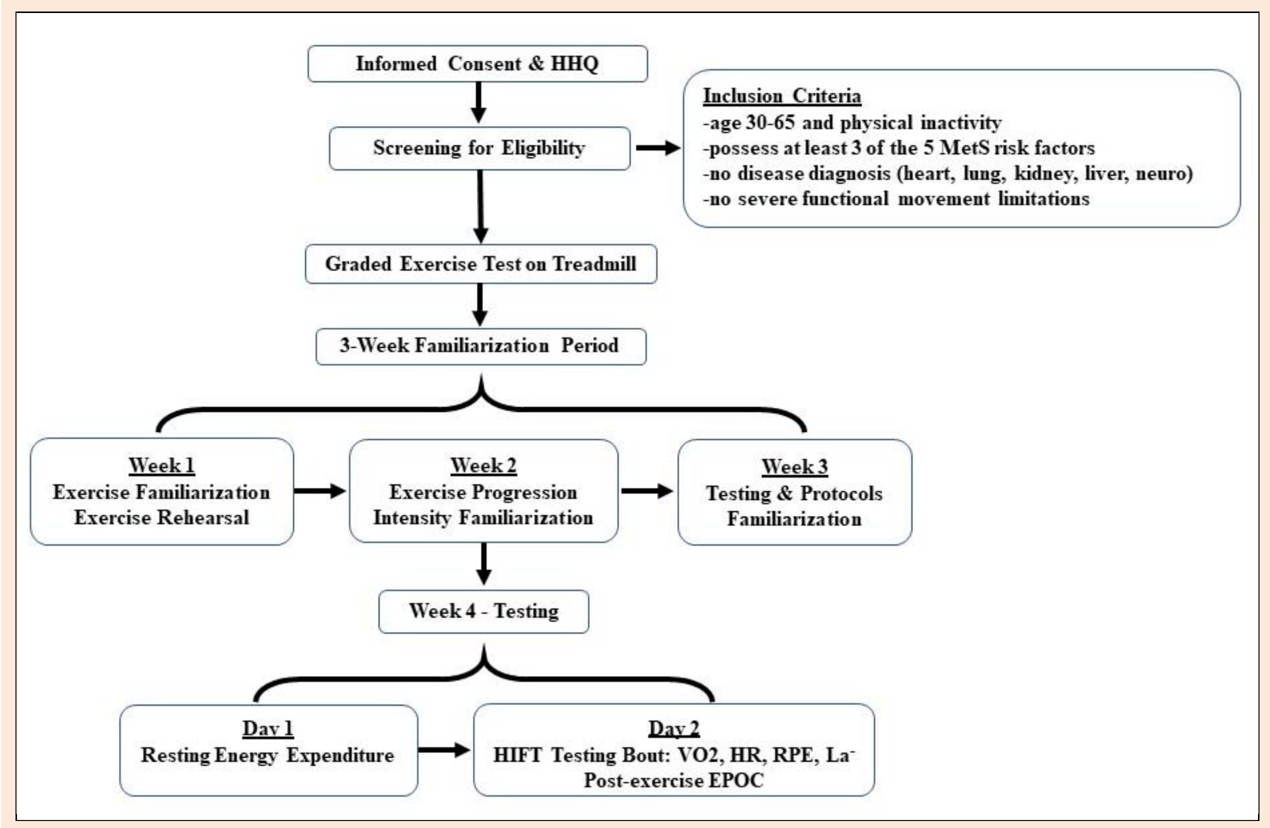

Figure 1. Experimental design. Health history questionnaire (HHQ). Metabolic syndrome (MetS). High intensity functional training (HIFT). Oxygen consumption (VO_2). Excess post-exercise oxygen consumption (EPOC). Heart rate (HR). Rating of perceived exertion (RPE). Blood lactate (La^-).

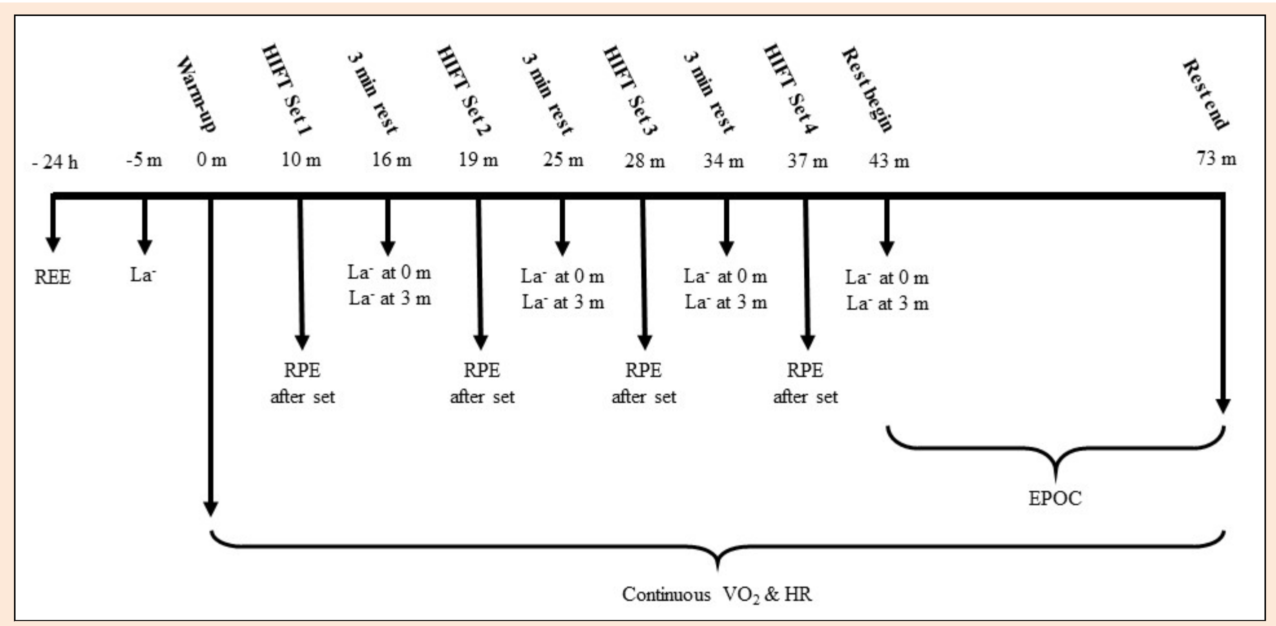

Figure 2. Testing Timeline. Resting energy expenditure (REE). Blood lactate (La^-). High intensity function training (HIFT). Session rating of perceived exertion (RPE). Oxygen consumption (VO_2). Heart rate (HR). Excess post-exercise oxygen consumption (EPOC). Hour (h). Minute (m).

3-Week familiarization period

Participants visited the HAP Lab twice a week for three weeks to familiarize and progress toward the HIFT testing session. Week 1 consisted of the functional movement screening (squat, lunge, hinge, push, pull, press, rotation), rehearsal of these movements, and learning the structured

HIFT routine using low-weight resistance equipment and reduced interval time, to minimize a training effect. Corrections and modifications were advised to ensure proper, safe exercise. If proper movement was not attained within Week 1, this familiarization was extended until satisfaction before progression. Week 2 consisted of rehearsing the structured HIFT routine adding appropriate resistance using bodyweight, or portable equipment such as suspension bands, boxes, medicine balls, kettlebells, dumbbells, and small barbells; aiming for a reported RPE 7-9 after each set (Crawford et al., 2018; Day et al., 2004; Tibana et al., 2018). Interval time remained reduced to minimize a training effect but simultaneously prepare the participants adequately. Week 3 consisted of two rehearsals of the HIFT testing bout at the target intensity of a post-set HR ±10bpm of VT2. Additionally, subjects were appropriately progressed in interval time reaching the target volume by the final session. The final session was also performed under fasting conditions while wearing the VO_2 measuring equipment and the lactate measuring procedures were rehearsed.

Resting energy expenditure

Participants arrived at the HAP Lab in the morning after a 12-hr fast and were outfitted with a HR monitor and metabolic cart. They rested in a supine position for 30 min in a silent, dimly-lit room, while gas exchange and HR data were continuously collected. REE was calculated from 15 min of energy expenditure data that maintained steady-state (<10% fluctuation in VO_2 and <5% fluctuation in respiratory exchange ratio (RER)) (Melanson et al., 2002; Weir, 1949).

HIFT testing session

The routine began with a 10-min warm-up of low-intensity cardiovascular exercise, dynamic stretching, and movement preparation drills. The conditioning phase of the HIFT session consisted of four 6-min sets with 3-min rests in between. Each set included a round of an aerobic priming exercise, lower body resistance exercise, upper body resistance exercise, and core strengthening exercise. Participants were asked to perform as many rounds as possible (AMRAP) of these 4 exercises within the 6-min set. All participants performed the same number of prescribed repetitions within each exercise but the amount of resistance was individualized to achieve a session RPE between 7-9 (Crawford et al., 2018; Day et al., 2004; Tibana et al., 2018). Total work time was 24 min; total rest time was 12 min, equating to a work to rest ratio of 2:1. See Table 1 for HIFT testing session example.

Exercise energy expenditure

Prior to performing the HIFT testing session, participants were outfitted with a HR monitor and metabolic cart. Aerobic EE was calculated using collected gas exchange data during exercise as well as during the 30 min EPOC period. Anaerobic EE was calculated using the change in lactate from peak after each AMRAP set minus the previous recovery or resting lactate, and then converted to oxygen equivalents. Total EE was determined by the sum of aerobic (collected gas exchange) and anaerobic (lactate-oxygen equivalents) energy expenditures.

Lactate was measured via fingerprick and collected in duplicate with two Lactate Plus Analyzers (Nova Biomedical, Waltham, MA). The duplicate lactate values were averaged. Baseline lactate was measured after a 5-min rest prior to commencement of the HIFT testing session. During the 3 min rest periods after each of the four AMRAP sets, lactate was measured immediately and then within the last minute. This identified a peak and recovery lactate for each set.

Change in lactate was calculated by subtracting baseline from peak lactate after the first set, then for sets 2-4 the previous recovery lactate was subtracted from the following peak lactate. The differences between the peak and recovery lactates for each of the 4 sets were totaled.

Table 1. HIFT Testing Session Example. High-intensity functional training (HIFT). As many rounds as possible (AMRAP).

Elapsed Exercise Time (Min)	Exercise Description	Work Time	Rest Time
Warm Up (Min 0)	Neck, wrist, & ankle circles, march in place, hip circles, jumping jacks, arm circles Slow sumo squats, donkey kicks, bird/dogs, 20 sec plank, light jog in place	10 min	
AMRAP Set 1 (Min 10)	20 Jumping Jacks 6 Goblet Squats 8 TRX Chest Press 10 Plank Frog Hops	6 min	
Rest Interval (Min 16)			3 min
AMRAP Set 2 (Min 19)	20 Butt Kicks 6 Dumbbell Step-ups 8 TRX Rows 10 Med Ball Russian Twists	6 min	
Rest Interval (Min 25)			3 min
AMRAP Set 3 Min 28	20 High Knees 6 Barbell Deadlifts 8 Dumbbell Push/Press 10 Plank Knee Drives	6 min	
Rest Interval (Min 34)			3 min
AMRAP Set 4 Min 37	20 Skaters 6 Box Jumps/Jump tucks 8 TRX Bicep Curls 20sec High Plank	6 min	
Rest Interval (Min 43)			3 min

This total was converted to oxygen equivalent values as 3 mL O_2·kg body weight per mmol of lactate (Scott, 2006). These oxygen equivalent values as well as the collected gas values were converted to kcal as 1L of O_2 = 5 kcal.

Statistical analysis

Participant characteristics and physiological responses are presented as mean ± SD, percentages, or individualized as appropriate and separated by sex. RPE data are presented as median with interquartile range (IQR). One-way repeated measures ANOVA was used to compare the differences between each time point of peak La^-, peak $\%VO_{2max}$, and peak %VT2 with a Tukey post-hoc test for multiple comparisons. A Friedman test was used to compare the differences between time points for RPE with a Wilcoxon Signed Rank test for multiple comparisons. Relationships between body weight, REE, session EE, work EE, rest EE and EPOC were analyzed using a Pearson's r. The significance level was set at $p \leq .05$. Analyses were performed in GraphPad Prism (GraphPad Software, San Diego, CA) and Microsoft Excel (Microsoft Corporation, Redmond, WA).

Results

Fifteen individuals expressed interest in volunteering for the study, with thirteen of them meeting the eligibility criteria (Male = 5, Female = 8), which met a prior sample size calculation minimum N = 12 ($\alpha = 0.05$, $\beta = 0.95$, ES = 0.5). These thirteen participants all completed baseline testing, a 3-week familiarization period, and 2 consecutive testing days, with no adverse reactions. All participants were considered sedentary (exercised < 30min/d, 3d/wk for at least 3mo) (Liguori et al., 2021). Participant characteristics are presented in Table 2. The results for individual and group (mean ± SD) EE are presented in Table 3. The group average EE of the total session was 270 ± 77.3 kcal; with lactate-attributed kcal supplying approximately 5% and EPOC supplying approximately 8% of the total EE. A Pearson correlation coefficient revealed multiple, significant ($p < 0.05$), positive relationships between body weight, REE, session EE, work EE, rest EE, and EPOC, see Table 4.

Table 2. Participant Characteristics and Metabolic Risk Factors. Data are presented as Mean (± SD).

Participant Characteristics	N=13
Height (m)	1.72 (0.10)
Weight (kg)	89 (23)
Age (yrs)	47 (10)
Maximal Oxygen Consumption (mL/kg/min)	25 (7)
Metabolic Syndrome Risk Factors	
Waist Circumference (cm)	107 (16)
Systolic BP (mmHg)	130 (13)
Diastolic BP (mmHg)	91 (12)
Triglyceride (mg/dL)	159 (77)
HDL-C (mg/dL)	52 (20)
FBG (mg/dL)	98 (13)
Additional Metabolic Risk Factors	
LDL-C (mg/dL)	135 (33)
Non-HDL-C (mg/dL)	167 (36)
TG/HDL-C Ratio	4 (3)
SAD (cm)	22 (5)

Blood pressure (BP). High-density lipoprotein cholesterol (HDL-C). Fasting blood glucose (FBG). Low-density lipoprotein cholesterol (LDL-C). Triglyceride (TG). Sagittal abdominal diameter (SAD).

Within the four 6-min AMRAP sets, peak VO_2 ranged between 130.6 ± 17.8% and 145.2 ± 21.8% of VT1, 88.8 ± 12.3% and 99 ± 12% of VT2, and 72.8 ± 10.7% and 81.5 ± 8.8% of VO_{2max}. Figure 3 illustrates group exercise intensity in terms of %VT2 for each minute of the HIFT session and the mean La^- at each measurement time point. Exercise intensity in terms of the mean RPE stated after each work set is shown in Figure 4. The change in La^- used to calculate anaerobic EE is also shown in Figure 4. A one-way ANOVA revealed no significant differences across all time points for peak La^- ($p = 0.16$). There was a significant increase in RPE across time from set 1 to set 4 [from 7 (6.5-8.0) to 8 (8.0-9.0); $\chi^2 = 29.4$; $p = 0.0001$; df = 3], see Figure 4. There was a significant time effect on peak $\%VO_{2max}$ (F (2.7, 32.2) = 6.82; $p = 0.002$) and peak %VT2 (F (2.5, 29.7) = 6.89; $p = 0.002$) as well. Specifically, peak $\%VO_{2max}$ in set 4 (77.2%) was significantly lower than set 2 (84.5%; $p = 0.005$) and 3 (83.5%; $p = 0.02$). The same time effect was found for peak %VT2, as set 4 (93.9%) was significantly lower than set 2 (102.8%; $p = 0.007$) and 3 (101.7%; $p = 0.03$).

Table 3. Individual and group energy expenditure. Data are presented individually as well as Mean (± SD).

Sex (M/F)	BW (kg)	REE (kcal/min)	Session EE (kcal-REE)	Work EE (kcal-REE)	Rest EE (kcal-REE)	EPOC EE (kcal-REE)	La- EE (kcal-REE)	La- % of EE (%)	Warm Up EE (kcal/min)	Work EE (kcal/min)	Rest EE (kcal/min)
F	115	1.4	293	194	49	26	24	8.1	6	9	5
F	74	0.9	200	145	24	20	11	5.5	3	6	3
F	89	1.5	245	176	40	14	14	5.8	5	7	5
F	83	1	197	145	27	15	10	5.3	4	6	3
F	62	.8	240	169	33	23	14	5.9	4	7	4
F	91	1.1	267	197	49	11	10	3.6	5	8	5
F	58	.9	191	141	29	14	8	4.0	3	6	3
F	65	1	163	126	23	8	6	3.6	3	5	3
M	105	1.2	293	186	56	28	23	7.8	5	8	5
M	89	1.1	265	181	43	27	14	5.1	4	8	4
M	137	1.6	408	281	62	46	19	4.7	7	12	7
M	115	1.5	382	278	54	32	19	4.9	7	11	6
M	87	1.3	369	273	63	21	12	3.4	6	11	6
Female	80(19)	1.1(.2)	225(44)	162(26)	34(11)	16(6)	12(5)	5.2(1.5)	4(1)	7(1)	4(1)
Male	107(21)	1.3(.2)	343(61)	240(51)	56(8)	31(9)	17(4)	5.2(1.6)	6(1)	10(2)	6(1)
Group	90(23)	1.2(.3)	270(77)	192(53)	43(14)	22(10)	14(6)	5.2(1.5)	5(1)	8(2)	5(1)

Body weight (BW). Resting energy expenditure (REE). Energy expenditure (EE). Excess post-exercise oxygen consumption (EPOC). Blood lactate (La^-).

Table 4. Pearson correlation coefficient. Data are presented as Pearson's r values.

	BW	REE	Session EE	Work EE	Rest EE	EPOC
BW	1.0					
REE	.85*	1.0				
Session EE	.82*	.76*	1.0			
Work EE	.75*	.74*	.98*	1.0		
Rest EE	.78*	.73*	.93*	.90*	1.0	
EPOC	.78*	.56*	.80*	.70*	.65*	1.0

* p = < .05. Body weight (BW). Resting energy expenditure (REE). Energy expenditure (EE). Excess post-exercise oxygen consumption (EPOC).

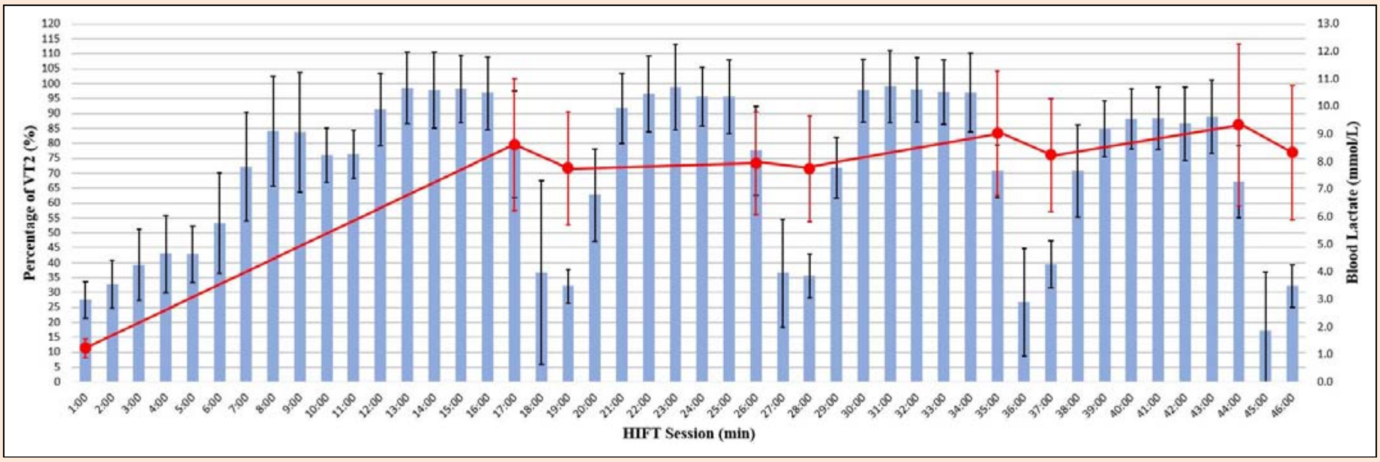

Figure 3. Exercise intensity in terms of %VT2 and Lactate. Data are presented as Mean ± SD. Second ventilatory threshold (VT2). High Intensity Functional Training (HIFT).

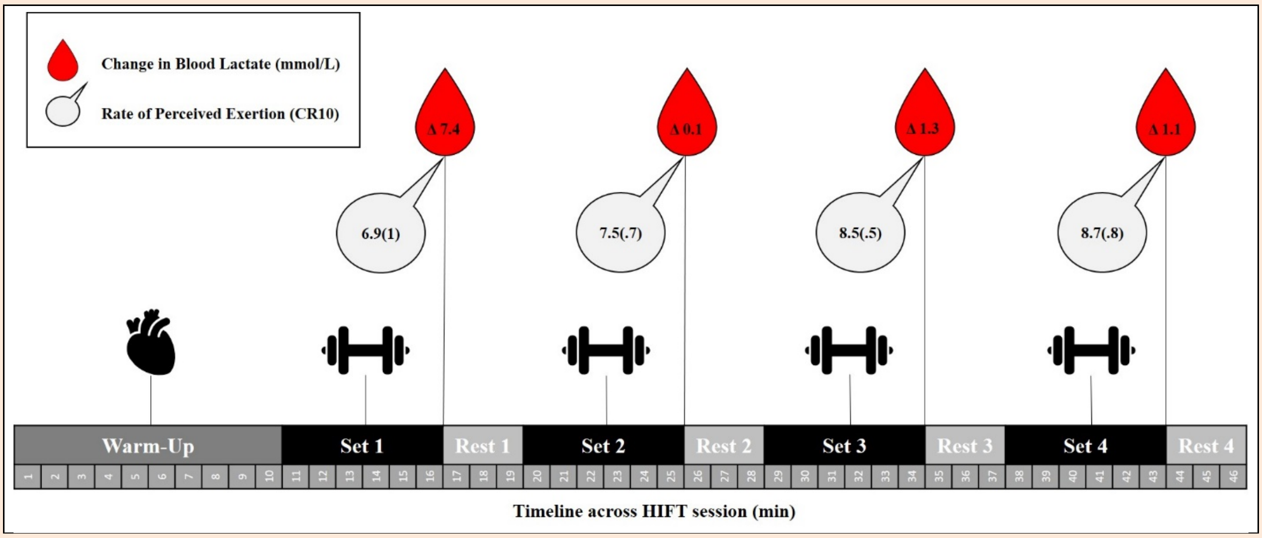

Figure 4. Illustration of RPE and Change in Lactate along timeline of HIFT session. RPE is presented as Mean (± SD). Change in Lactate is presented as the difference between peak and the previous recovery value. Rating of perceived exertion (RPE). High intensity functional training (HIFT).

Discussion

The results of the present study suggest that HIFT is an effective exercise modality to increase daily energy expenditure in minimal time. A recommendation for the clinical management of MetS is a reduction in daily caloric intake of at least 500 kcal (Grundy et al., 2004; Myers et al., 2019). With a group mean session energy expenditure of 270 ± 77.3 kcal above REE, which was achieved in less than 1 hour of exercise, HIFT offers a tool for increasing daily energy expenditure, contributing to over half of the recommended caloric deficit (Grundy et al., 2004; Myers et al., 2019). To our knowledge, the present study is the first to explore these effects in a sedentary, clinical population, unfamiliar with this modality. With only 6 familiarization sessions, these individuals were able to reach the exercise intensity and duration to achieve this amount of energy expenditure.

A novel method of the current study is the inclusion of blood lactate energy expenditure in addition to indirect calorimetry (Scott, 2006). Benito et al. (2016) explored the contribution of blood lactate to the total energy expenditure after 3 exercise routines each consisting of combinations of circuit resistance exercise and aerobic exercise, the common components of HIFT (Benito et al., 2016). Similar to the present study, researchers measured lactate immediately after the work intervals and at the end of the rest intervals and repeated these measurements for each set (Benito et al., 2016). With comparable peak lactate values to our study (CM = 10.7 ± 3.2, FW = 9.4 ± 3.2, CE = 5.8 ± 2.3 mmol/L), these authors found that the lactate energy expenditure significantly contributed 1.9% to 7.1% ($p<0.05$) of the total kcal expenditure (Benito et al., 2016). The average lactate-attributed kcal expenditure of the current study was 5.19 ± 1.48% of the total kcal expenditure, falling within the range of the previous study. These results demonstrate that even modest contributions, if not accounted for, lead to an underestimation of total energy expenditure, and therefore lactate-attributed kcal warrant measurement in modalities involving resistance exercise.

Our study demonstrated that HIFT has a profound effect on EPOC, showing an average 21.9 ± 10.1 kcal expenditure above REE for the 30 mins after workout completion. Post-exercise energy expenditure is important to report with HIFT interventions, as the individual components of high aerobic intensity and resistance exercise are shown to elicit greater EPOC than isocaloric moderate intensity steady-state aerobic exercise (Greer et al., 2015). Greer et al. (2015) demonstrated that the elevated oxygen consumption above REE remained high at 12 hours and 21 hours after completion of high aerobic intensity and resistance exercise (Greer et al., 2015). The current study did not measure EPOC past 30 mins, however it is possible that HIFT could have a lasting effect even 21 hours later, as this workout combines the two components measured in the Greer et al. (2015) study. To our knowledge, this is the first study to report the effect of HIFT on EPOC.

With the increase in fatty-acid turnover during EPOC (Lundsgaard et al., 2020), the prolonged utilization of this substrate may have positive implications on improving MetS risk factors. One of the metabolic signatures of MetS is an over-abundance of stored and circulating fatty acids, which lead to the hallmark risk factors of high TG, low HDL-C, and visceral adiposity (Toth, 2014). After 6 weeks of HIFT in a similar population, Fealy et al. (2018) noted such an effect. Significant reductions in plasma TG ($p<.05$), reductions in visceral adiposity ($p<.05$), reductions in mean arterial pressure (MAP) ($p<.05$), and improvements in oral glucose tolerance test (OGTT) response, which led to a 110% improvement in the participants MetS z-score ($p<.05$) were noted (Fealy et al., 2018). The authors did not report EPOC energy expenditure, however, our preliminary findings of the effect of HIFT on EPOC could point to a possible mechanism underlying the improvements shown in the Fealy et al. (2018) paper. This gives reason for reporting EPOC energy expenditures in the literature to help determine which exercise interventions prolong fatty-acid turnover, therefore with potential for improving MetS risk factors.

Another aim of the present study that adds to the novelty, is determination of the VO_2 responses to HIFT in relationship to the participant's VTs. Within the four 6-min AMRAP sets, VO_2 ranged between 88.8 ± 12.3% and 99.0 ± 12.0% of VT2, indicating a very high aerobic effort. To our knowledge, this is the first study to report intensity of HIFT in relationship to ventilatory thresholds. Two other studies reported average intensities of a HIFT session stated ~ 80% HR_{max} (Willis et al., 2019) and ~ 92.1% HR_{max} (Browne et al., 2020). Although the intensity representation differs from the current study, all of above indicate a very-high, vigorous effort (Liguori et al., 2021).

Measured VTs are more accurate in reflecting the individual metabolic situation compared to calculated cutpoints such as %HRR, %HR_{max}, or %VO_{2max} (Keir et al., 2022). Knowing the intensity of exercise based on these VTs can optimize the exercise prescription to each individual and increase training responsiveness. This was shown twice when the training responsiveness to a %VT intensity prescription was compared to a %HRR intensity prescription (Weatherwax et al., 2019; Wolpern et al., 2015). Both studies found that 100% of the %VT group had positive training responses whereas only 60% and 41.7% respectively, of the %HRR group responded favorably (Weatherwax et al., 2019; Wolpern et al., 2015). With the ultimate goal of achieving a training response with exercise interventions, using threshold-based intensity prescription is a good practice. In a 12-week exercise intervention comparing a threshold-based prescription to a HRR-based prescription, of the participants considered to have MetS, 100% of the threshold-based group improved their MetS z-score whereas only 83% of the HRR-based group improved their MetS z-score (Weatherwax et al., 2018), once again demonstrating superiority of a threshold-based program.

As mentioned earlier, HIFT workout design is unlimited. A workout can vary in total duration, work to rest ratios, the number of repetitions and order of exercises, as well as the amount of resistance applied to each exercise. Commonly though, exercise intensity is considered very high or vigorous and the workout involves both cardiorespiratory and resistance modalities. Because of this variety, reporting energy expenditure in kcal/min allows for comparison between different designs. To our knowledge, four studies of differing HIFT designs have reported kcal/min (Brisebois et al., 2021; Browne et al., 2020; Morris et al., 2019; Willis et al., 2019). With males and females combined, the sessions averaged 15.1 kcal/min for 35 min (Browne et al., 2020), 7.5 kcal/min for 45 min (Brisebois et al., 2021), 10.8 kcal/min for 44 min (Willis et al., 2019), and 9.7 kcal/min for 15 min (Morris et al., 2019). An average of 5.7 kcal/min for 45 min was found in the present study which includes the warm-up and the rest intervals. Two of the above studies did not include the warm-up data and had rest intervals less than 10 sec, as well as involved participants that regularly exercised and had no metabolic risk factors (Browne et al., 2020; Morris et al., 2019). These factors could have contributed to the higher kcal/min expenditure than the present study. Brisebois et al. (2021) and Willis et al. (2019) also included the warm-up and rest intervals in their averages of 7.5 kcal/min and 10.8 kcal/min respectively, similar to the current study (Brisebois et al., 2021; Willis et al., 2019). Population differences exist however with both previously mentioned studies involving individuals with no metabolic risk factors (Brisebois et al., 2021; Willis et al., 2019) and one population being considered trained (Brisebois et al., 2021). These factors could also contribute to the differences in kcal/min from the current study.

The small sample size and relative number of male and female participants represent limitations to the current study. Accordingly, we present the individual body weight and EE data in Table 3 to allow the reader a nuanced understanding of the consequential variability in these measures. Additionally, EE data are presented in Table 3 as kcal/min for each individual as well as the group, in order to aid in designing future exercise interventions targeting energy expenditure.

Conclusion

Based on our results, HIFT may be a time-efficient alternative to the traditional exercise recommendations for adults seeking to use exercise as a tool to improve MetS risk factors. This study has shown the potential of implementing HIFT in a sedentary population, burdened with metabolic risk factors, as they were able to produce the requisite effort after only 6 sessions of familiarization. Future trials should be designed to determine the training dose of HIFT to see clinically meaningful changes in the risk factors of MetS.

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Key points

- Mean energy expenditure for a 46-minute session of high intensity functional training was 270 kcal.
- VO_2 during the work intervals fell at or very near to the second ventilatory threshold indicating a vigorous effort.
- Peak blood lactate ranged between 7.9 and 9.3 mmol, contributing to approximately 5% of total energy expenditure.

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