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Research article

A Preliminary Investigation into the Frequency Dose Effects of High-Intensity Functional Training on Cardiometabolic Health

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Abstract

The objective of this study was to explore the effects of three weekly frequency doses of high-intensity functional training (HIFT) on an array of cardiometabolic markers in adults with metabolic syndrome (MetS). Twenty-one men and women, randomized into one (HIFT1), two (HIFT2), or three (HIFT3) days per week of HIFT, completed 3-weeks of familiarization plus a 12-week progressive training program. Pre- and post-intervention, several cardiometabolic, body composition, oxygen consumption, metabolic syndrome severity, and perceptions of fitness measurements were assessed. Additionally, an exercise enjoyment survey was administered post-intervention. A Cohen's *d* was used to demonstrate within-group change effect size. Although this study was not fully powered, a one-way and two-way ANOVA were used to compare the dose groups to provide provisional insights. No differences were found when frequency dose groups were compared. Many cardiometabolic, body composition, and fitness improvements were seen within each group, with clinically meaningful improvements in the metabolic syndrome severity score (MSSS) (HIFT1: -0.105, $d = 0.28$; HIFT2: -0.382, $d = 1.20$; HIFT3: -0.467, $d = 1.07$), waist circumference (HIFT1: -4.1cm, $d = 3.33$; HIFT2: -5.4cm, $d = 0.89$; HIFT3: -0.7cm, $d = 0.20$), and blood glucose (HIFT1: -9.5mg/dL, $d = 0.98$; HIFT2: -4.9mg/dL, $d = 1.00$; HIFT3: -1.7mg/dL, $d = 0.23$). All three groups similarly reported high exercise enjoyment and likeliness to continue after the intervention. In conclusion, HIFT performed once, twice, or thrice a week elicits improvements in MetS and is considered enjoyable. HIFT, even at a low weekly dose, therefore represents a potential strategy to reduce the global MetS burden.

Key words: Metabolic Syndrome, Lipids, Insulin, Ventilatory Threshold.

Introduction

Metabolic syndrome (MetS), a condition that consists of five interconnected cardiometabolic risk factors, (ATP III, 2002; Grundy et al., 2005) increases the potential of developing atherosclerotic cardiovascular disease (ASCVD), Type 2 Diabetes (T2D), and several common cancers (Esposito et al., 2012; Hunt et al., 2004; Laing et al., 2003; Lakka, 2002; Palmer and Toth, 2019). The reported prevalence of MetS is as high as 31% in the global adult population (Noubiap et al., 2022); rendering it as a predominant driver of the worldwide crisis of poor cardiovascular health, cancer, and T2D (Dattani et al., 2019; World Health Organization, 2020). Regular exercise has a profound effect in improving the risk factors included in MetS (Dalleck et al., 2014; 2013; Roberts et al., 2013); therefore, weekly minimum amounts have been established, recommended, and disseminated globally (Liguori et al., 2021). Despite the plethora of evidence demonstrating the benefits of exercise, only 1 in 4 adults worldwide meet these recommendations (Whitfield et al., 2021; World Health Organization, 2022). The most common reported barriers to this are "lack of time," "lack of facilities," and "lack of motivation" (Costello et al., 2011; Justine et al., 2013). This information highlights the imperative to create strategies that overcome these barriers, and to investigate the efficacy of these strategies in reducing the global MetS burden.

Increasing in popularity is a form of exercise known as High-Intensity Functional Training (HIFT); that combines vigorous aerobic and resistance exercises into a time-efficient workout (Feito et al., 2018; Kercher et al., 2023). There are a range of design options for HIFT workouts, often requiring minimal equipment and allowing adaptability to various physical settings (Browne et al., 2020; Feito et al., 2018). HIFT has been shown to elicit positive psychological affect, and participation adherence, as well as high exercise enjoyment and strong intentions to continue (Heinrich et al., 2020; 2014). HIFT might therefore be a viable strategy for increasing exercise participation given its potential to alleviate known barriers.

The efficacy of HIFT at reducing MetS severity is emerging. In a study (Fealy et al., 2018) of 13 middle-aged adults clinically diagnosed with non-insulin dependent T2D, HIFT performed 3 times per week for 6 weeks improved diastolic blood pressure (DBP) ($p < 0.01$) and blood triglycerides (TG) ($p < 0.05$). Reductions (albeit insignificant) in waist circumference (WC) and systolic blood pressure (SBP) were also experienced (Fealy et al., 2018). The improvement in these risk factors resulted in a reduction in the MetS z-score ($p = <0.001$); an estimate of health risk based on the five MetS risk factors (Fealy et al., 2018; Gurka et al., 2014). In another study (Feito et al., 2019) of 18 overweight/obese adults, but metabolically healthier than the participants in the study by Fealy et al., (2018), 8-weeks of HIFT was compared to 8-weeks of the established exercise recommendations (Ligouri et al., 2021) to see if differences occurred in glucose control and WC. Even though baseline measures were not considered within the MetS range, WC improved, albeit insignificantly in both groups (Feito et al., 2019). To our knowledge, the majority of HIFT research has used healthy populations, therefore more scientific inquiry is needed to determine the effect on MetS in a symptomatic cohort.

The five risk factors used to diagnose MetS have

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developed over years of consultation among many organizations (Alberti et al., 2006; 1998; ATP III, 2002; Balkau and Charles, 1999). The aim was to establish simple criteria to confirm this syndrome in the clinical setting. Despite having established cut-offs for diagnosis, it is understood that a spectrum exists within these risk factors, and that another set of *underlying* risk factors (i.e. insulin resistance, atherogenic dyslipidemia, endothelial dysfunction, abnormal body fat distribution) give rise to these criteria (Grundy et al., 2005). It has been proposed that these additional underlying risk factors be included in investigations for the prevention and treatment of MetS (Alberti et al., 2006). Fealy et al., (2018) explored insulin resistance proxy markers by conducting an oral glucose tolerance test (OGTT) and calculating an insulin sensitivity score, and also body fat distribution via dual-energy x-ray absorptiometry (DEXA). The researchers found that insulin sensitivity improved in this population ($p < 0.05$), postulated as an overall downward shift in the glucose response to the OGTT (Fealy et al., 2018). They also saw regional reductions in body fat, notably android fat ($p < 0.05$), gynoid fat ($p < 0.01$), trunk fat ($p < 0.05$), and leg fat ($p < 0.0001$) (Fealy et al., 2018). In this same population, pancreatic β-cell function was measured as the mathematical product of insulin secretion and sensitivity, before and after a 6-week HIFT intervention (Nieuwoudt et al., 2017). Improvements were seen in these T2D adults ($p < 0.05$), representing more efficiency in the processing of insulin within the pancreatic β-cells (Nieuwoudt et al., 2017).

These studies indicate the potential positive effect HIFT may have on metabolic dysfunction, warranting further exploration into the previously mentioned underlying risk factors. Additionally, the participants in the above-mentioned studies exercised 3 times per week and therefore it is unknown if improvements could be seen with lower weekly frequency prescriptions. Minimal dose exercise research has been explored in other modalities, but not with HIFT (Batrakoulis et al., 2019; Grgic et al., 2018; Schoenfeld et al., 2019; Stavrinou et al., 2018). Establishing minimal doses offers more insight into solutions for the exercise barrier of "lack of time." For these reasons, our aim was to investigate the weekly frequency dose-effects of HIFT on an array of blood lipids and lipoproteins, glucose, insulin and the homeostatic assessment of insulin resistance (HOMA-IR), metabolic syndrome severity, and body composition in adult men and women with MetS. Furthermore, we aimed to report their perceptions of exercise enjoyment and intention to continue after 12-weeks of different weekly doses of HIFT.

Methods

Study design and participants

This was a 12-week randomized, three-arm, parallel-group, dose-response trial conducted between March and December 2022. The SPIRIT guidelines for reporting clinical trials were followed (Chan et al., 2013), the protocol was published (Smith et al., 2022a), and the study was registered at clinicaltrials.gov (NCT05001126). A total sample size of 60 participants was projected, with a recruitment aim of 15 participants per cohort across 4 successive training periods (Smith et al., 2022a). This expectation was set pre-pandemic. Unfortunately, the unforeseen changes due to COVID-19 delayed and limited recruitment to two successive cohorts, and therefore our study should be interpreted as a preliminary investigation. Participants were recruited via newspaper advertisements, employee listservs, physician referral, flyers, and word of mouth. Interested participants reviewed and signed the informed consent, and study eligibility was determined through a health history questionnaire and cardiometabolic screening. Inclusion criteria included physically inactive men and women between the ages of 35 - 65 years, with at least 3 cardiometabolic risk factors for MetS (ATP III, 2002), without any diagnosis of heart, lung, kidney, liver, or neurological disease, and without any medical or orthopedic conditions preventing participation in exercise. Two cohorts from the planned four were recruited; 13 participants for the first cohort (recruitment March-April 2022) and 14 participants for the second cohort (recruitment July-August 2022). This study was approved by the ethics committee of Auckland University of Technology (AUT) [21/79] and Human Research Committee of Western Colorado University (WCU) [HRC2020-01-01-R04].

Eligible participants began the study with baseline metabolic bloodwork and body composition testing at Gunnison Valley Health hospital (GVH). Participants visited the lab at GVH after a 12-hr overnight fast, phlebotomy was performed, then participants went to the radiology department for body composition testing. Twenty-four to 48 hours after, participants visited the High Altitude Performance Lab (HAP Lab) at WCU and performed a graded exercise test with verification bout as well as completed the Simple Lifestyle Indicator Questionnaire (SLIQ) and International Fitness Scale (IFIS). Participants were asked to maintain all current nutrition and lifestyle behaviors as indicated on their SLIQ throughout the period of the study. Upon completion of baseline testing, participants were randomized into one of three intervention arms: HIFT1, 1 session per week; HIFT2, 2 sessions per week; or HIFT3, 3 sessions per week. All participants began the exercise intervention with a 3-week familiarization period that included 2 training sessions per week. In the fourth week, participants began training according to their allocated frequency dose group for the next 12 weeks. The 12 weeks were periodized into three 4-week phases, where duration of work intervals was increased and/or rest intervals were decreased each phase. The final week of each phase was de-loaded to 65% of the volume before progressing to the next phase. Participants repeated all baseline tests and questionnaires 48-72 hrs after completion of the training, scheduling to allow 48 hrs of rest before phlebotomy and body composition testing. One additional questionnaire was added at post-testing to evaluate participants' feelings of enjoyment and intention to continue regarding the HIFT exercise.

Procedures

Eligibility screening

Interested participants visited the HAP Lab in a fasted state and completed the informed consent and health history questionnaire. Participants rested in a seated position for 5-

min then blood pressure (BP), heart rate (HR), and blood oxygen saturation (S_aO_2) were measured in duplicate. Next, 40 uL of capillary blood was collected via finger prick and analyzed for total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, triglycerides, and glucose using the Cholestech LDX Analyzer (Abbott Diagnostics, Abbott Park, IL). Last, participant's stature, weight, waist circumference (Ligouri et al., 2021), and sagittal abdominal diameter (Van Guilder and Kjellsen, 2020) were measured.

Blood analysis

Nine mL of blood were drawn via venipuncture of the antecubital vein by a phlebotomist at GVH. Fasting insulin, glucose, HbA1c, hematocrit, and a lipoprotein metabolism profile (LMP) were analyzed at GVH or Mayo Clinic in Denver, CO. The LMP consisted of apolipoprotein B (ApoB), lipoprotein (a) (Lp(a)), total cholesterol (TC), total triglyceride (TG), low-density lipoprotein cholesterol (LDL-C) and triglyceride (LDL-T), very low-density lipoprotein cholesterol (VLDL-C) and triglyceride (VLDL-T), and high-density lipoprotein cholesterol (HDL-C). Hematocrit was used to adjust for plasma volume changes and applied to the cholesterol and triglyceride measures. Glucose and insulin measures were used to calculate the homeostatic model assessment of insulin resistance (HOMA-IR) (Matthews et al., 1985; Sarafidis et al., 2007).

Body composition

Dual-energy X-ray absorptiometry (DEXA) was used to measure lean, fat, and bone mass and percent of total mass for whole and regional sections of the body (Lunar Prodigy DF+512070, GE Healthcare, Chicago, IL). All scans were performed by a radiologist at GVH. Waist circumference and sagittal abdominal diameter were repeated at post-testing.

Graded exercise test

A walking graded exercise test was performed on a power treadmill (CT850, Spirit Fitness, Jonesboro, AR) while continuous VO_2 (TrueOne 2400, Parvo Medics, Salt Lake City, UT) and HR (Polar F1, Polar USA, Warminster, PA) were measured. Workload and Rating of Perceived Exertion (RPE) (Borg CR10) was recorded in the last seconds of each minute of the test. The test began with a 5-min warm-up at a self-selected pace, gradually increasing each minute to the pace for the remainder of the test. A modified Balke and Ware protocol was used where participants maintained their constant speed and incline was increased by 1% each minute until volitional exhaustion (Balke and Ware, 1959). After the initial bout, participants rested passively for 20 mins then performed a verification bout to confirm VO_{2max}. The verification bout consisted of a 3-min warm-up then immediately progressed to the equivalent workload of 105% of their max during the exercise test (last fully completed stage) and continued until volitional exhaustion. If the VO_{2peak} of the verification bout and graded exercise test were within ± 3%, true VO_{2max} was considered achieved (Astorino et al., 2009; Weatherwax et al., 2016). Maximal VO_2 and maximal workload were recorded. Determination of the first ventilatory threshold (VT1) and second ventilatory threshold (VT2) was performed in duplicate through visual inspection of gas exchange data. Ventilatory equivalents of O_2 (V_E/VO_2) and ventilatory equivalents of CO_2 (V_E/VCO_2) were plotted across time and secondly, ventilation (V_E) was plotted across VO_2. VT1 occurred when V_E/VO_2 increased without concurrent increase in V_E/VCO_2, whereas VT2 occurred when both V_E/VO_2 and V_E/VCO_2 simultaneously increased. In the second graph, VT1 occurred at the first a-linear increase in V_E and VT2 occurred at the second a-linear increase in V_E. The points that VT1 and VT2 occurred were compared between both graphs, and an absolute VO_2 (L/min) and workload (MET) were established at these time points.

Self-perceived fitness and exercise enjoyment questionnaires

Individual perception of fitness was assessed at baseline and 12-weeks using the International Fitness Scale (IFIS) (Merellano-Navarro et al., 2017). The scale contained 5 questions with the Likert-type answering options (very poor = 1, poor = 2, average = 3, good = 4, and very good = 5) associated to the elements of physical fitness: general fitness, cardiorespiratory endurance, muscular strength, speed-agility, and flexibility. During post-testing only (approximately 48-72 hrs after completion of intervention), participants completed a modified Physical Activity Enjoyment Scale (PACES) to assess "enjoyment" of the previously completed exercise, with two additional questions assessing "intention to continue" the exercise (Heinrich et al., 2020; Kendzierski and DeCarlo, 1991; Kwan and Bryan, 2010). The PACES was an 18-item, 7-point, bipolar rating scale. Example items are "I find it unpleasurable = 1/I find it pleasurable = 7" and "It is not at all refreshing = 1/It is very refreshing = 7." Two additional questions were added following a similar 7-point scale asking 1. How likely the participant would continue performing that modality (Not likely = 1/Very likely = 7) and 2. How many days per week the participant would consider performing that modality (No days per week = 0/Seven days per week = 7).

Number of MetS risk factors

According to the National Cholesterol Education Program (NCEP) MetS criteria, the average number of MetS risk factors (MetS RF) were calculated for each frequency dose group pre- and post- intervention (ATP III, 2002).

Metabolic syndrome severity score

A mean MetS severity score (MSSS) was determined for each frequency dose group pre- and post- intervention using the Metabolic Syndrome Severity Calculator (Gurka et al., 2014). This calculation incorporates the value for each MetS risk factor as well as sex- and ethnicity-specific population data to establish a z-score, which coincides with each standard deviation beyond the population mean (mean 0, SD = 1). The MSSS z-score describes one's relationship to the population mean, where higher scores represent an increase in MetS severity (Gurka et al., 2014). Rather than using the categorical cut-off points of the MetS criteria (ATP III, 2002), using this continuous representation of

MetS severity offers more insight into incremental changes.

HIFT intervention

Each HIFT session began with a 10-min warm-up consisting of low-intensity aerobic exercise, dynamic stretching, and movement preparation drills, then concluded with a 5-min cool-down consisting of static stretching. The conditioning period of the HIFT session consisted of 4 sets, each including 4 functional exercises from the following categories: 1) aerobic, 2) lower body strength, 3) upper body strength, and 4) trunk/core strength. The exercises were designed to use minimal and portable equipment such as dumbbells, kettlebells, medicine balls, etc. The amount of load for each exercise was individualized aiming for a reported exertion of an RPE ≥ 7. One round consisted of performing a standardized amount of repetitions or seconds of the 4 functional exercises, back-to-back, in the order listed above. Participants completed as many rounds as possible (AMRAP) in a prescribed amount of time for the completion of one set. Participants rested for a prescribed amount of time, then repeated this format for a total of 4 sets. All sessions within a week were standardized to ensure consistency of training among the three dose groups with only frequency differing. The total length of each HIFT session was 55 mins or less, including the warm-up and cool-down. Additional details of the HIFT exercises and progression characteristics can be found here (Smith et al., 2022a).

Statistical analysis

Data from participants who completed ≥ 80% of the intervention were included and analyzed using GraphPad Prism (GraphPad Software, San Diego, CA) and SPSS 29.0 (IBM Corp., Armonk, NY). Data are presented as mean (M) and standard deviation (SD), or median (Mdn) and interquartile ranges (IQR), with Cohen's *d* effect sizes (*d*) and 95% confidence intervals (CI). Effect sizes were considered very weak (*d* = 0.00 - 0.19), weak (*d* = 0.20 - 0.49), moderate (*d* = 0.50 - 0.79), strong (*d* = 0.80 - 1.19), very strong (*d* = 1.20 - 1.99), and extremely strong (*d* ≥ 2.00) (Sawilowsky, 2009). Group differences in baseline variables were compared using a one-way ANOVA or Kruskal-Wallis test. For group comparisons of outcome variables, a two-way ANOVA was used to determine the "time" effect of the combined groups, the frequency dose "group" effect, and if a "group x time" interaction occurred. In the case of missing data, a mixed-effects model was used. We arbitrarily set significance at $p \leq 0.050$, acknowledging that our analyses should be interpreted as provisional indications given they are not fully powered.

Results

Twenty-seven participants were enrolled, 4 participants withdrew due to health complications unrelated to the study (HIFT1: N = 3; HIFT2: N = 1) and 2 dropped out due to unforeseen family and work interruptions (HIFT1: N = 1; HIFT2: N = 1). Twenty-one participants completed the full intervention (HIFT1: N = 4, HIFT2: N = 8, HIFT3: N = 9) with an adherence rate between 85-100%. Participant characteristics from the eligibility screening (Table 1) and all baseline outcome variables were similar between groups ($p > 0.050$). A Wilcoxon test revealed no differences in pre-to-post SLIQ for each group ($p > 0.050$) indicating participants maintained their current lifestyle behaviors throughout the intervention period.

Table 1. Participant baseline characteristics from eligibility screening. Data are means (±SD).

	HIFT1 (n=4)	HIFT2 (n=8)	HIFT3 (n=9)	*p-value*
M/F, n (%)	3 (75%), 1 (25%)	5 (63%), 3 (37%)	3 (33%), 6 (67%)	-
Age (yrs)	55.3 (7.7)	51.1 (11.6)	56.3 (9.6)	0.646
BMI (kg/m²)	32.7 (6.2)	29.8 (5.7)	31.6 (6.0)	0.589
VO_{2max} (mL/kg/min)	30.6 (2.0)	31.2 (8.6)	25.8 (4.5)	0.202
WC (cm)	112.5 (9.0)	109.7 (17.6)	111.5 (17.3)	0.831
SBP (mmHg)	132.0 (10.7)	134.4 (17.4)	144.1 (12.3)	0.207
DBP (mmHg)	88.5 (9.0)	93.4 (10.9)	100.0 (10.1)	0.090
TG (mg/dL)	143.3 (60.0)	166.8 (58.3)	175.7 (78.1)	0.568
HDL-C (mg/dL)	40.5 (19.4)	54.6 (22.8)	44.7 (19.4)	0.562
GLU (mg/dL)	106.0 (20.8)	99.8 (6.1)	103.2 (14.9)	0.922
LDL-C (mg/dL)	143.0 (45.3)	112.0 (37.1)	144.4 (42.0)	0.196
Non-HDL-C (mg/dL)	171.8 (50.2)	145.6 (36.1)	179.8 (44.2)	0.105
TG/HDL-C Ratio	5.2 (5.5)	3.9 (2.6)	5.3 (4.0)	0.884

Maximum oxygen consumption (VO_{2max}). Waist circumference (WC). Systolic blood pressure (SBP). Diastolic blood pressure (DBP). Triglyceride (TG). High-density lipoprotein cholesterol (HDL-C). Blood glucose (GLU). Low-density lipoprotein cholesterol (LDL-C).

Table 2-5 present the baseline (Pre) and 12-week follow-up (Post) data for each of the frequency dose groups, and includes the within group effect sizes and 95% confidence intervals. The preliminary two-way ANOVA and mixed-effects *p*-values are also included. Table 6 presents the one-way ANOVA results for the 12-week follow-up (Post) time point only.

Blood Analysis

The metabolic blood marker results are presented in Table 2. There were no differences between the frequency dose groups for all blood markers. A time effect was seen for GLU ($p = 0.004$), HOMA-IR ($p = 0.029$), and LDL-T ($p = 0.020$).

Body Composition

Table 3 displays the results for each body composition measurement. There were no differences between the frequency dose groups for any body composition marker. A group effect was seen for % fat tissue ($p = 0.034$) and % lean tissue ($p = 0.046$); as well as a time effect for % bone tissue ($p = 0.020$), waist circumference ($p = 0.005$), and sagittal abdominal diameter ($p = 0.005$).

Graded exercise test

The graded exercise test results are presented in Table 4. There were no differences between the frequency dose groups for any measurement. A time effect was seen for VO_2 at VT1 ($p = 0.010$), workload at VT1 ($p = 0.014$), VO_2 at VT2 ($p = 0.021$), and workload at VT2 ($p = 0.011$).

Table 2. Within-group change and ANOVA results in blood analysis markers.

	HIFT1 (n = 4)			HIFT2 (n = 8)			HIFT3 (n = 9)			ANOVA		
	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Group *p-value*	Time *p-value*	G×T *p-value*
GLU (mg/dL)	107.8 (22.8)	98.3 (17.0)	0.98 [-0.30, 2.17]	100.3 (7.0)	95.4 (8.5)	1.00 [0.12, 1.85]	99.8 (5.2)	98.1 (9.6)	0.23 [-0.44, 0.88]	0.711	0.004	0.197
INS (mcIU/mL)	12.6 (6.7)	9.2 (2.5)	0.78 [-0.41, 1.88]	18.2 (15.4)	9.8 (4.6)	0.58 [-0.19, 1.32]	12.5 (4.0)	11.4 (4.6)	0.52 [-0.19, 1.21]	0.687	0.061	0.292
HOMA-IR (mg/dL)	3.6 (2.7)	2.3 (1.1)	0.77 [-0.41, 1.88]	4.5 (3.5)	2.4 (1.2)	0.64 [-0.15, 1.39]	3.1 (1.1)	2.8 (1.3)	0.40 [-0.30, 1.07]	0.839	0.029	0.262
HbA1c (%)	5.8 (0.2)	5.7 (0.2)	0.39 [-0.66, 1.38]	5.5 (0.3)	5.5 (0.2)	0.23 [-0.48, 0.92]	5.8 (0.4)	5.7 (0.3)	0.20 [-0.47, 0.86]	0.171	0.313	0.979
ApoB (mg/dL)	113.0 (31.1)	110.5 (25.2)	0.24 [-0.78, 1.22]	90.5 (19.6)	85.4 (12.9)	0.35 [-0.38, 1.05]	111.7 (25.1)	107.4 (19.8)	0.39 [-0.30, 1.06]	0.082	0.187	0.942
TC (mg/dL)	212.3 (27.8)	210.5 (24.3)	0.11 [-0.80, 1.08]	193.4 (58.3)	188.3 (33.7)	0.17 [-0.53, 0.87]	220.8 (50.0)	213.8 (40.0)	0.44 [-0.26, 1.11]	0.435	0.387	0.927
LDL-C (mg/dL)	133.8 (36.9)	126.5 (35.6)	0.65 [-0.49, 1.71]	112.6 (42.5)	109.9 (24.7)	0.12 [-0.59, 0.81]	140.4 (32.3)	137.4 (28.1)	0.21 [-0.46, 0.87]	0.223	0.321	0.912
VLDL-C (mg/dL)	28.3 (25.7)	29.8 (16.7)	0.15 [-1.13, 0.85]	29.3 (14.6)	24.4 (11.5)	0.37 [-0.36, 1.08]	25.0 (9.9)	21.6 (7.3)	0.38 [-0.31, 1.05]	0.705	0.383	0.636
HDL-C (mg/dL)	46.0 (17.5)	46.8 (11.8)	0.11 [-1.09, 0.88]	51.5 (21.3)	54.0 (15.0)	0.27 [-0.96, 0.45]	51.6 (20.2)	50.8 (22.1)	0.13 [-0.53, 0.78]	0.858	0.634	0.660
TG (mg/dL)	179.0 (167.7)	184.0 (129.5)	0.12 [-1.09, 0.88]	172.3 (63.3)	148.1 (44.5)	0.57 [-0.20, 1.31]	145.0 (53.3)	133.0 (48.5)	0.39 [-0.30, 1.06]	0.634	0.251	0.460
LDL-T (mg/dL)	63.3 (56.6)	46.5 (24.5)	0.52 [-0.58, 1.54]	42.5 (10.3)	32.4 (6.4)	1.59 [0.50, 2.64]	39.7 (9.5)	39.8 (12.4)	0.01 [-0.67, 0.64]	0.304	0.020	0.162
VLDL-T (mg/dL)	99.0 (106.4)	96.3 (62.5)	0.06 [-0.93, 1.04]	110.4 (56.1)	98.0 (42.3)	0.35 [-0.38, 1.05]	86.1 (41.2)	77.8 (35.9)	0.39 [-0.31, 1.05]	0.667	0.312	0.888
TG/HDL-C ratio	5.1 (6.1)	4.7 (4.5)	0.25 [-0.77, 1.23]	4.2 (2.7)	3.2 (1.9)	0.86 [0.02, 1.66]	3.3 (1.8)	3.2 (1.8)	0.11 [-0.55, 0.76]	0.648	0.096	0.358

High-intensity functional training (HIFT). One-day per week (HIFT1). Two-days per week (HIFT2). Three-days per week (HIFT3). Glucose (GLU). Insulin (INS). Homeostatic model assessment of insulin resistance (HOMA-IR). Glycosylated hemoglobin (HbA1c). Apolipoprotein B (ApoB). Total cholesterol (TC). Low-density lipoprotein cholesterol (LDL-C). Very low-density lipoprotein cholesterol (VLDL-C). High-density lipoprotein cholesterol (HDL-C). Triglyceride (TG). Low-density lipoprotein triglyceride (LDL-T). Very low-density lipoprotein triglyceride (VLDL-T). Group by time interaction (G×T).

Table 3. Within-group change and ANOVA results in body composition measurements.

	HIFT1 (n=4)			HIFT2 (n=8)			HIFT3 (n=9)			ANOVA		
	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Group *p-value*	Time *p-value*	G×T *p-value*
TM (kg)	98.9 (18.2)	97.1 (17.8)	1.67 [0.04, 3.24]	87.4 (16.0)	86.0 (15.3)	0.50 [-0.26, 1.22]	92.7 (25.8)	93.2 (26.0)	0.16 [-0.81, 0.51]	0.666	0.174	0.269
FM (kg)	34.1 (5.3)	33.9 (7.2)	0.11 [0.03, 2.34]	30.3 (9.0)	29.0 (7.6)	0.51 [-0.25, 1.23]	38.8 (12.3)	38.7 (12.9)	0.07 [-0.59, 0.51]	0.210	0.277	0.500
LM (kg)	61.5 (13.9)	60.1 (12.0)	0.52 [-0.52, 1.54]	54.1 (10.7)	54.4 (10.0)	0.12 [-0.81, 0.58]	51.0 (15.4)	52.0 (14.9)	0.59 [-1.29, 0.14]	0.508	0.862	0.143
BM (kg)	3.2 (1.0)	3.0 (0.8)	0.71 [-0.45, 1.79]	3.1 (0.6)	3.0 (0.5)	0.71 [-0.09, 1.48]	2.7 (0.6)	2.7 (0.7)	0.19 [-0.84, 0.48]	0.402	0.053	0.152
FT (%)	34.8 (3.7)	35.0 (4.0)	0.08 [-1.05, 0.91]	33.9 (6.9)	33.5 (5.7)	0.20 [-0.51, 0.89]	41.8 (6.3)	41.2 (6.1)	0.46 [-0.24, 1.14]	0.034	0.517	0.788
LT (%)	61.7 (3.4)	61.9 (3.5)	0.08 [-1.06, 0.91]	61.9 (7.0)	63.1 (5.4)	0.55 [-1.28, 0.22]	55.2 (6.0)	56.0 (5.7)	0.57 [-1.26, 0.16]	0.046	0.176	0.589
BT (%)	3.3 (0.8)	3.2 (0.5)	0.63 [-0.50, 1.68]	3.6 (0.6)	3.5 (0.4)	0.78 [-0.04, 1.56]	3.0 (0.5)	2.9 (0.4)	0.51 [-0.20, 1.20]	0.089	0.020	0.999
AF (%)	44.8 (3.6)	45.0 (4.0)	0.04 [-1.02, 0.94]	44.9 (7.1)	40.2 (9.3)	0.87 [0.03, 1.68]	51.5 (8.3)	49.9 (9.9)	0.51 [-0.20, 1.19]	0.115	0.093	0.225
GF (%)	38.0 (5.8)	35.4 (6.8)	0.99 [-0.29, 1.18]	37.5 (7.8)	36.5 (6.0)	0.16 [-0.54, 0.85]	44.1 (7.4)	42.2 (7.2)	0.84 [0.05, 1.59]	0.133	0.094	0.851
WC (cm)	112.5 (9.0)	108.4 (7.9)	3.33 [-0.65, 6.03]	109.7 (17.6)	104.3 (13.4)	0.89 [0.04, 1.70]	112.1 (17.1)	111.4 (17.4)	0.20 [-0.47, 0.86]	0.816	0.005	0.134
SAD (cm)	23.9 (3.3)	23.1 (3.3)	1.47 [-0.04, 2.11]	23.1 (5.5)	22.3 (5.0)	0.97 [0.10, 1.81]	23.8 (4.3)	23.6 (4.8)	0.25 [-0.43, 0.90]	0.901	0.005	0.309

High-intensity functional training (HIFT). One-day per week (HIFT1). Two-days per week (HIFT2). Three-days per week (HIFT3). Total mass (TM). Fat mass (FM). Lean mass (LM). Bone mass (BM). Fat tissue (FT). Lean tissue (LT). Bone tissue (BT). Android fat (AF). Gynoid fat (GF). Waist circumference (WC). Sagittal abdominal diameter (SAD). Group by time interaction (G×T).

Self-perceived fitness and exercise enjoyment questionnaires

Table 5 presents the results for the self-perceived fitness questionnaire. There were no differences between the

frequency dose groups. A time effect was seen for increased perception of cardiorespiratory fitness ($p = 0.006$), muscular strength ($p = 0.000$), speed & agility ($p = 0.006$), and flexibility ($p = 0.002$).

Results for the exercise enjoyment questionnaire are displayed in Table 6. The three frequency dose groups reported similarly high enjoyment as well as likeliness to continue and reported a similar amount of days per week they would prefer to perform HIFT.

Number of MetS risk factors and MSSS

Figure 1 illustrates the changes in number of MetS risk factors and MSSS pre- and post-intervention for each group. No differences were found between the frequency dose groups for either marker, however a time effect was seen for both ($p < 0.001$ and $p = 0.002$, respectively). Of note, the reduction in MetS risk factors resulted in a very strong effect size in HIFT1 ($d = 1.31$, [-0.13, 2.66]), a moderate effect size in HIFT2 ($d = 0.71$, [0.61, 2.89]), as well as a very strong effect size in HIFT3 ($d = 1.41$, [0.45, 2.34]). Secondly, the reduction in MSSS effect size for HIFT1 was considered weak ($d = 0.28$, [-0.74, 1.26]); whereas HIFT2 was considered very strong ($d = 1.20$, [0.25, 1.10]) and HIFT3 was considered strong ($d = 1.07$, [0.22, 1.89]).

Discussion

The purpose of this investigation was to explore the effects of different weekly frequencies of a 50 - 55 min HIFT protocol for 12 weeks in order to elucidate a minimal weekly 'frequency' dose for meaningful improvements in MetS. The pooled time effect we observed for many health markers indicated positive change regardless of frequency, providing provisional insight that lower weekly frequency

Table 4. Within-group change and mixed-effects results in graded exercise test measurements.

	HIFT1 (n = 3)			HIFT2 (n = 7)			HIFT3 (n = 8)			Mixed-Effects		
	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Group *p-value*	Time *p-value*	G × T *p-value*
VO_{2max} (mL/kg/min)	30.6 (2.0)	33.8 (1.7)	0.83 [-2.13, 0.59]	31.2 (8.6)	31.8 (8.7)	0.19 [-0.93, 0.56]	25.8 (4.5)	24.1 (4.0)	0.46 [-0.29, 1.176]	0.055	0.374	0.098
WL_{max} (MET)	10.0 (1.5)	10.9 (0.8)	0.20 [-1.32, 0.97]	10.1 (3.9)	10.6 (3.1)	0.20 [-0.94, 0.56]	8.4 (1.4)	8.5 (1.6)	0.31 [-0.82, 0.57]	0.263	0.419	0.902
VO_2/VT1 (L/min)	1.4 (0.3)	1.7 (0.5)	1.87 [-3.87, 0.18]	1.2 (0.3)	1.3 (0.3)	0.46 [-1.23, 0.43]	1.3 (0.6)	1.3 (0.4)	0.19 [-0.89, 0.51]	0.407	0.010	0.136
WL/VT1 (MET)	3.7 (0.7)	4.5 (0.8)	0.59 [-1.79, 0.71]	3.7 (0.8)	4.2 (1.0)	0.78 [-1.62, 0.10]	3.5 (0.7)	3.9 (0.7)	0.48 [-1.20, 0.27]	0.489	0.014	0.772
VO_2/VT2 (L/min)	2.1 (0.4)	2.4 (1.0)	0.78 [-1.88, 0.41]	2.0 (0.6)	2.3 (0.7)	1.36 [-2.39, -0.28]	1.9 (0.9)	2.0 (0.8)	0.08 [-0.77, 0.62]	0.623	0.021	0.193
WL/VT2 (MET)	6.6 (0.7)	8.1 (1.9)	0.62 [-1.83, 0.70]	7.4 (2.3)	8.4 (2.7)	2.47 [-4.01, -0.91]	6.3 (1.1)	7.5 (2.7)	0.79 [-1.62, 0.10]	0.603	0.011	0.960

High-intensity functional training (HIFT). One-day per week (HIFT1). Two-days per week (HIFT2). Three-days per week (HIFT3). Maximal oxygen uptake (VO_{2max}). Workload (WL). First ventilatory threshold (VT1). Second ventilatory threshold (VT2). Group by time interaction (G×T).

Table 5. Within-group change and mixed-effects results in the self-perceived fitness questionnaire.

	HIFT1 (n=3)			HIFT2 (n=7)			HIFT3 (n=9)			Mixed-Effects		
	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Pre M (SD)	Post M (SD)	Cohen's *d* [95% CI]	Group *p-value*	Time *p-value*	G × T *p-value*
IFIS_GenFit	2.3 (0.6)	2.3 (1.3)	0.00 [-1.13, 1.13]	2.6 (0.7)	3.4 (0.8)	1.46 [-2.54, -0.34]	2.3 (0.5)	3.0 (0.9)	0.77 [-1.50, -0.00]	0.214	0.057	0.385
IFIS_CRF	1.7 (0.6)	2.5 (1.3)	0.32 [-1.46, 0.88]	2.3 (0.7)	3.3 (0.8)	2.27 [-3.70, -0.80]	2.1 (0.9)	2.9 (0.9)	0.71 [-1.43, 0.04]	0.362	0.006	0.917
IFIS_MusStr	2.3 (0.6)	3.0 (0.8)	1.16 [-2.64, 0.44]	2.3 (0.5)	3.4 (0.5)	3.02 [-4.83, -1.19]	2.1 (0.6)	3.1 (0.9)	1.16 [-1.99, -0.29]	0.742	0.000	0.564
IFIS_Spd/Agl	2.0 (0.0)	2.3 (0.5)	0.58 [-1.77, 0.72]	2.0 (0.8)	2.9 (0.7)	0.80 [-1.64, 0.09]	1.7 (0.7)	2.4 (1.0)	1.17 [-2.01, -0.29]	0.484	0.006	0.571
IFIS_Flex	1.7 (0.6)	2.5 (1.0)	1.00 [-2.39, 0.51]	1.8 (0.9)	2.4 (0.8)	0.34 [-1.09, 0.44]	2.2 (0.8)	3.3 (0.9)	1.42 [-2.35, -0.46]	0.113	0.002	0.751

High-intensity functional training (HIFT). One-day per week (HIFT1). Two-days per week (HIFT2). Three-days per week (HIFT3). International Fitness Scale (IFIS). General fitness (GenFit). Cardiorespiratory fitness (CRF). Muscular strength (MusStr). Speed and agility (Spd/Agl). Flexibility (Flex). Group by time interaction (G×T).

Table 6. Exercise enjoyment questionnaire results.

	HIFT1 (n = 4) Mdn (IQR)	HIFT2 (n = 7) Mdn (IQR)	HIFT3 (n = 9) Mdn (IQR)	*p-value*
PACES Total Score (18 - 126)	108.0 (94.5-123.0)	109.0 (103.0-110.0)	105.0 (97.5-114.0)	0.847
PACES Average Score (1 - 7)	6.0 (5.3-6.8)	6.1 (5.7-6.1)	5.8 (5.4-6.3)	0.945
Likeliness to Continue Score (1 - 7)	5.5 (5.0-6.8)	6.0 (6.0-7.0)	6.0 (5.5-7.0)	0.561
Preferred Dose Per Week Score (1 - 7)	3.0 (3.0-3.0)	3.0 (2.0-3.0)	3.0 (3.0-3.5)	0.439

High-intensity functional training (HIFT). One-day per week (HIFT1). Two-days per week (HIFT2). Three-days per week (HIFT3). Physical Activity Enjoyment Scale (PACES).

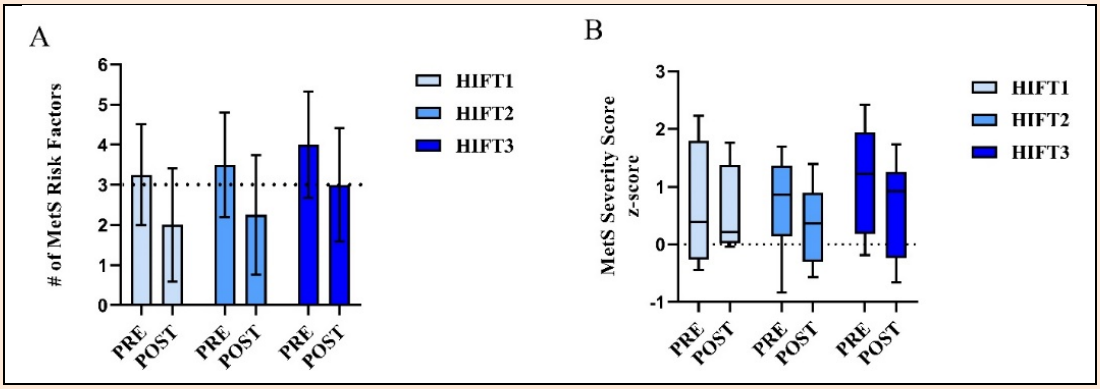

Figure 1. Metabolic syndrome severity. A) Columns represent group means, error bars represent group standard deviation. Dotted line represents the number of risk factor cut-off for MetS diagnosis. B) Line within boxes represents group means, error bars represent group standard deviations. Box limits represent group max and min. Dotted line represents the 50th percentile within the population. Metabolic syndrome (MetS). High-intensity functional training (HIFT). One-day per week (HIFT1). Two-days per week (HIFT2). Three-days per week (HIFT3).

doses elicited positive responses. These time effects were seen for blood glucose, HOMA-IR, LDL-T, waist circumference, sagittal abdominal diameter, the number of MetS risk factors, and the MSSS. Time effects for improvements in VO_2 and workload at both VT1 and VT2 were also found. Additionally, HIFT increased the participants' perception of cardiorespiratory fitness, muscular strength, speed & agility, and flexibility, regardless of dose group. In the exercise enjoyment survey, all three groups reported similar PACES scores, falling within the 80th and 85th percentile, and reported similarly on the "likeliness to continue" question within the 80th and 89th percentile. This indicates that regardless of the weekly frequency, relatively high enjoyment was experienced. Once again, all three groups reported within a similar range (3.0 - 3.3 days out of 7) on the "preferred dose per week" question.

A noteworthy finding, and of clinical relevance, is the reduction in MSSS we found in all three groups. The MSSS serves as a severity biomarker of metabolic derangement and addresses disease risk along a continuum rather than the defined risk factor cut-off points. The MSSS parallels the physiological continuum of development of metabolic dysfunction and therefore represents not only absolute disease risk but further residual risk beyond risk factor cut-off points (DeBoer et al., 2017; Golden et al., 2002; Gurka et al., 2017). In a study by DeBoer et al. (2018), the MSSS was used to track risk for future development of T2D and ASCVD for a 5-year period after a 1-year lifestyle or metformin intervention, in 2,476 adults with prediabetes. The researchers calculated 1-year change in MSSS effect sizes as well as hazard ratios for prediction of future disease for both interventions (DeBoer et al., 2018). They found a MSSS reduction effect size for the lifestyle intervention of 0.62 and effect size for metformin of 0.23. Upon risk prediction analysis, DeBoer et al. (2018) found that the degree of reduction in MSSS was associated with a proportional reduction in risk for future T2D and ASCVD (DeBoer et al., 2018). This demonstrates that a MSSS reduction effect size as little as 0.23 has health benefits and therefore is clinically meaningful. In our study, we found a MSSS reduction effect size of 0.28 for the HIFT1 group, which is similar to the metformin intervention mentioned previously. Our HIFT2 group saw the strongest effect size of 1.20, with HIFT3 only slightly lower at 1.07. If the degree of reduction in MSSS is proportionally associated with a reduction in risk for future disease, HIFT2 demonstrates the strongest clinical relevance for improving MetS severity. Not only is this clinically meaningful, but HIFT2 is practically meaningful as the time commitment is only 2 hours per week. Similarly, the individuals with T2D in the Fealy et al. (2018) study experienced a reduction in MSSS (-110%, $p < 0.001$). This was a larger percent reduction than our study, however this could be due to a greater baseline MSSS in the Fealy et al. (2018) participants thus permitting more room for improvement.

DeBoer et al. (2018) looked at the individual MetS risk factors and what proportion of the reduction in disease risk was attributable to each, noting that waist circumference and blood glucose changes provided a proportion of T2D risk prediction similar to that of changes in MSSS (75.0%, 48.2%, and 61.6%, respectively) (DeBoer et al., 2018). The magnitude of change in these risk factors proportionally reduced the risk for T2D (DeBoer et al., 2018). Their findings corroborate the clinical importance of the waist circumference and blood glucose changes we saw in our study. All dose groups demonstrated improvements in waist circumference (HIFT1: -4.1cm, HIFT2: -5.4cm, HIFT3: -0.7cm) and blood glucose (HIFT1: -9.5mg/dL, HIFT2: -4.9mg/dL, HIFT3: -1.7mg/dL), potentiating proportional risk reduction in T2D. Fealy et al. (2018) and Feito et al. (2019) noted reductions, albeit insignificant in waist circumference (-2.0 cm, $p = 0.11$ and -1.4 cm, $p > 0.05$, respectively) less than our HIFT1 and HIFT2 groups, but greater than our HIFT3 group. Additionally, Nieuwoudt et al. (2017) reported improvements in blood glucose (-4.9 mg.dL, $p = 0.19$) similar to our HIFT2 group, but less than our HIFT1 and greater than HIFT3. Comparable to the trend seen in MSSS, HIFT2 resulted in strong effects for these predictive markers.

To our knowledge, this is the first exploration using a population with MetS, distinct from T2D and overweight/obese, as well as the first exploration into a minimal effective weekly HIFT frequency. We postulate though, that the differences, in regards to waist circumference and blood glucose, between what we found and what was reported in Fealy et al. (2018), Nieuwoudt et al. (2017), and

Feito et al. (2019), could perhaps indicate an influence of chronic dose, rather than simply weekly frequency. The participants in Fealy et al. (2018) and Nieuwoudt et al. (2017) completed 18 total HIFT sessions (3x/wk for 6 wks) and the participants in Feito et al. (2019) completed 24 total HIFT sessions (3x/wk for 8 wks). All three studies had a greater chronic dose than our HIFT1 group at 12 total sessions, were close to our HIFT2 group at 24 total sessions, but less than our HIFT3 group at 36 total sessions. All three studies along with our HIFT1 and HIFT2 groups had greater improvements in waist circumference and blood glucose than our HIFT3 group.

We speculate that the total volume dose for HIFT3 could have been more physiological stress than what was beneficial for this population. In a review of the inflammatory responses of HIFT, interleukin-6 (IL-6) was found to be acutely elevated after a training session, returning to basal levels at 48 hrs (Jacob et al., 2020), although in asymptomatic men and women with HIFT training experience. This acute inflammatory response though, is attributed to the hormetic effect leading to the desired exercise adaptations. Inflammatory markers, particularly IL-6 and C-reactive protein (CRP), can also be present in the body without the physiological stress of exercise, and represent a marker of systemic inflammation that predicts future atherosclerotic events (Ridker et al., 2000a; 2000b). This is often proposed as one of the reasons individuals with MetS have a greater risk for ASCVD, as CRP (Festa et al., 2000) and IL-6 (Van Guilder et al., 2006) chronically accompany MetS. Our participants, potentially in a chronic pro-inflammatory state, were subjected to progressive volumes of the acute inflammatory response of HIFT, with inversely reduced periods of recovery between sessions. Perhaps the coupled inflammatory stress of MetS and the HIFT exercise, reached a point of limited benefit in the HIFT3 group, who experienced the most volume and least recovery. Parallels of chronic IL-6 are seen in studies of excessive exercise training with reduced recovery in healthy populations, which disrupts the hormetic balance (Da Rocha et al., 2019). As a result, insulin signaling was impaired in multiple organs (Da Rocha et al., 2019) as well as impaired skeletal muscle glucose tolerance (Flockhart et al., 2021). Although we did not measure inflammatory markers in our participants, this could be a plausible reason for the diminishing benefits in glucose and waist circumference seen in our HIFT3 group, as both are known to be linked to insulin resistance.

With an additional barrier to exercise adherence being reported as "lack of motivation" (Costello et al., 2011; Justine et al., 2013), and knowing that higher ratings of enjoyment are linked to whether people are motivated to continue the exercise behavior (Kwan and Bryan, 2010), we wanted to know how our participants rated their enjoyment and intention to continue and if there were differences in the frequency groups. Our findings demonstrated that regardless of how many times per week the participants performed HIFT, their ratings of enjoyment and intention to continue were not different, and all groups rated above the 80th percentile of possible scores; a higher score meaning higher enjoyment. Our findings conflict with Ekkekakis et al. (2011). These authors state that feelings of pleasure and enjoyment decrease after exercise intensity surpasses the first ventilatory threshold (Ekkekakis et al., 2011). However, our intervention required exercise well beyond this intensity, with VO_2 ranging between 88.8 ± 12.3% and 99.0 ± 12.0% of the second ventilatory threshold (Smith et al., 2022b), yet our participants still reported pleasure. Some high-intensity interval training (HIIT) intervention studies suggest that when exercising at higher intensities, the shorter the intervals (1 to 2 minutes) elicit greater enjoyment than longer intervals (20 - 40 minutes) (Jung et al., 2014; Martinez et al., 2015). Our intervention required intervals of 6 minutes, repeated 4 times (Smith et al., 2022a). Our findings are in line with Heinrich et al. (2014), where enjoyment and intention to continue was compared between a HIFT protocol and combined protocol following the ACSM published guidelines. The HIFT participants spent less time exercising than the other group, and reported greater enjoyment and intention to continue (Heinrich et al., 2014). Differing from the HIIT protocols in the previous studies, HIFT incorporates greater variety of movement with the resistance exercise component (Feito et al., 2018). It is suggested that the variety of exercises involved in HIFT may cause new participants to focus on mastery-based goals (Partridge et al., 2014), which has shown to foster intrinsic interest in the activity (Elliot and McGregor, 2001). Our intervention was delivered in a group setting which allowed for connection between the participants. In a similar HIFT group intervention evaluating the participants "sense of community," the authors found this perception to be highly rated and that it influenced their enjoyment of the study (Heinrich et al., 2022). Although we did not measure this affective response, perhaps our similar setting created this group dynamic that led to our higher ratings of enjoyment.

A strength to our study was the application of mesocycle periodization. Within a 4-week block, training load was strategically applied for 3 of the weeks followed by 1 week of reduced load, prior to a progression of load into the next 4-week block. This strategy provides adequate stimulation for training adaptation along with a recovery period to ensure physiological absorption of the adaptations and management of fatigue (Plisk and Stone, 2003). Given the intense nature of HIFT and the efficacy of this strategy shown by endurance and strength coaches (Turner, 2011), periodization was deemed appropriate for our population and duration of training. Our intention to conduct this intervention in a translatable, non-laboratory, real-world setting, was another strength. The modality of HIFT has the ability to be performed in group or solo situations, as well as in home, gym, work, outdoor, and travel physical settings requiring minimal equipment (Feito et al., 2018). This translatability proposes a solution to the "lack of facilities" barrier to exercise. But this real-world approach led to a limitation in our study, as the data collection period was within the COVID-19 pandemic. During this time several community infection surges occurred, masking and group size regulations were a moving boundary, and quarantine regulations were required with a positive COVID test. The delays, restrictions, and community concerns hindered our recruitment, contributing to our small sample size, leading to the study being underpowered (Corsello et

al., 2020). Additionally, it is unknown how much affect the residual health complications from COVID infections had on our participant's outcomes, but it had known effect on adherence. Throughout the study period, several of our participants tested positive for COVID, were symptomatic and required quarantine. Two participants had such severe infections they were unable to continue. This once again contributed to our small sample size. We encourage future studies to replicate and progress our research questions, as HIFT shows promise toward effectiveness and exercise adherence. To facilitate this, our full methodology is published (Smith et al., 2022a).

Conclusion

In summary, HIFT performed once, twice, or thrice weekly for 12 weeks similarly improved a range of cardiometabolic health markers in participants with MetS, and was regarded as an enjoyable modality of exercise.

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Key points

- High-intensity functional training performed once, twice, or thrice weekly for 12-weeks can improve metabolic syndrome severity.
- High-intensity functional training is time-efficient, reported to be enjoyable, translatable to various physical and social settings, and requires minimal equipment.
- High-intensity functional training is feasible for inexperienced individuals given adequate supervision and individualized prescription.

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