the Journal of Strength and Conditioning Research™

High-Intensity Functional Training Improves Cardiorespiratory Fitness and Neuromuscular Performance Without Inflammation or Muscle Damage

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Abstract

Posnakidis, G, Aphamis, G, Giannaki, CD, Mougios, V, Aristotelous, P, Samoutis, G, and Bogdanis, GC. High-intensity functional training improves cardiorespiratory fitness and neuromuscular performance without inflammation or muscle damage. *J Strength Cond Res* 36(3): 615–623, 2022—We examined the effects of high-intensity functional training (HIFT) on cardiorespiratory and neuromuscular performance, as well as on inflammatory and muscle damage markers. Thirteen physically active healthy volunteers (aged 28.3 ± 3.8 years, 5 men and 8 women) underwent 8 weeks of a group HIFT program performed 3 times per week. Each session consisted of 4 rounds of a 9-exercise circuit (30-second exercise and 15-second recovery). During the first and last weeks of training, venous blood was sampled daily to monitor changes in serum C-reactive protein (CRP) and creatine kinase (CK). After 8 weeks of HIFT, body fat decreased by 0.64 ± 1.01 kg ($p = 0.041$), maximal oxygen uptake improved by 1.9 ± 2.2 $ml \cdot kg^{-1} \cdot min^{-1}$ ($p = 0.009$), countermovement jump by 2.6 ± 1.5 cm ($p = 0.001$), bench press 1-repetition maximum (1RM) by 4.5 ± 3.8 kg ($p = 0.001$), maximum number of bench press repetitions at 65% 1RM by 4 ± 5 repetitions ($p = 0.03$), and abdominal muscle endurance by 6 ± 4 repetitions ($p < 0.001$). In both week 1 and week 8 of training, CK increased mildly in the morning after the first session of the week (main effect for day, $p = 0.008$), whereas no significant changes were observed in CRP ($p = 0.31$). During week 8, CK on all days was ~32% lower compared with week 1 (160 vs. 235 $U \cdot L^{-1}$; main effect of week 1 vs. week 8, $p = 0.027$), whereas CRP remained unchanged ($p = 0.225$). This HIFT program was effective in improving cardiorespiratory and neuromuscular physical fitness without causing significant inflammation or muscle damage in physically active subjects.

Key Words: C-reactive protein, creatine kinase, strength, maximal oxygen uptake

Introduction

During the past 2 decades, different forms of high-intensity interval training (HIIT) are gaining popularity due to their shorter exercise time, compared with conventional training methods, and efficiency in improving physical fitness and overall health parameters (26,38). Indeed, according to the results of the annual survey of worldwide fitness trends for 2019, HIIT is ranked third among fitness trends and has been among the top 3 every year since 2014 (40). A typical HIIT program consists of relatively brief, intense workouts lasting 20–30 minutes in total and is therefore considered a better option in terms of time efficiency compared with traditional exercise regimes (18). However, most HIIT regimes consist mainly of aerobic exercise modalities, such as running or cycling, leading to cardiovascular adaptations (18), whereas strength training elements are typically missing.

High-intensity functional training (HIFT) includes short bursts (e.g., 30 seconds) of either running, cycling, or rowing, as well as functional exercises, such as body weight bearing exercises (burpees, push-ups, etc.), and weight lifting (deadlift and thrusters) (13). This form of exercise is becoming popular in gym centers, possibly due to higher levels of enjoyment of the subjects compared with traditional forms of exercise (16,20) and increased exercise adherence (20), and its health and fitness benefits seem very promising (13). This is because HIFT results in improvements of several fitness components (e.g., increases in muscle strength, power, endurance, maximal oxygen uptake, and body composition), which may confer health benefits (e.g., improved glucose homeostasis and lower risk of developing cardiovascular disease) (13). The multimodal nature of HIFT programs may explain the favorable adaptations in a variety of physiological and physical fitness components, rather than on just a single component (12). The improvements in fitness parameters, such as cardiorespiratory fitness (21), strength (14,21), and flexibility (21), as well as in body composition and bone metabolism (14) reported in the literature may provide a measure of the effectiveness of this type of training (13).

Despite its overall effectiveness in improving different parameters of physical fitness, HIFT may impose high loads on the neuromuscular system, leading to increased muscle damage and inflammation. For instance, it is well known that resistance

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exercises used in HIFT, especially those that include eccentric contractions, can cause muscle damage and increased inflammation, as indicated by increases in creatine kinase (CK) and C-reactive protein (CRP) concentrations (9,32). However, the acute and chronic effects of HIFT programs on indices of muscle damage and inflammation have not been fully explored, whereas information on the effects of such programs on neuromuscular performance is still scarce.

Thus, the aim of this study was twofold: (a) to examine the effect of an 8-week HIFT program on cardiorespiratory and neuromuscular performance in healthy, physically active individuals and (b) to investigate the responses of inflammation and muscle damage indices to HIFT sessions at the beginning and end of the program.

Methods

Experimental Approach to the Problem

A repeated-measure design was used to investigate the effects of HIFT on physical fitness, body composition, and selected biochemical indices of inflammation and muscle damage over an 8-week period. Each HIFT session consisted of 9 exercises (30 seconds each with 15 seconds of rest) performed for 4 rounds. Subjects were trained as a group, 3 times per week. On the week before and the week after the training period, subjects underwent fitness and body composition assessment, including measurement of maximal oxygen uptake ($\dot{V}O_2max$), knee extension and flexion peak torque (isokinetic dynamometry), bench press 1-repetition maximum (1RM), vertical jump, muscle endurance (abdominal crunches and bench press at 65% 1RM), and body composition assessment (bioelectrical impedance). In addition, during the first and last weeks of training, blood samples were taken daily in the morning to monitor CK and CRP responses to the training sessions. Performance during training (i.e., number of repetitions during the 30 seconds for each exercise in rounds 1 and 4) was also recorded during the first and last weeks of training.

Subjects

Thirteen healthy, physically active adult volunteers participated in the study (5 men and 8 women, age range 21-38 years, 28.4 ± 3.8 years, mean ± *SD* throughout). Before the commencement of the study, all volunteers were examined by a medical doctor and received clearance to participate. Individuals were included in the study if they satisfied the following criteria: they were healthy men or women, aged between 18 and 45 years, were free of any acute musculoskeletal problem and any medication, had a BMI between 23 and 27 $kg \cdot m^{-2}$, and had been training with resistance and cardio exercise in the gym for more than 6 months (3–4 times per week). Smokers and individuals with chronic musculoskeletal or metabolic problems (e.g., diabetes) were excluded from the study. All subjects were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study This study was approved by the National Bioethics Committee of Cyprus (CNBC/2016/56), and all subjects signed an informed consent form, following written and verbal explanation of the nature, aim, and methodology of the study.

Procedures

After familiarization and baseline physical fitness testing, subjects followed a HIFT program 3 times per week for 8 weeks. In the first as well as in the eighth week of training, a venous blood sample was obtained in the morning of each weekday (Figure 1). After the end of the HIFT program, subjects repeated the anthropometric assessment and physical fitness tests. A detailed food and fluid consumption record was kept for 24 hours before the first visit to the laboratory, and the same diet was repeated 24 hours before the post-training tests. Post-training tests took place at least 72 hours after the last training session to allow adequate recovery, whereas subjects were asked to refrain from any strenuous exercise the day before testing. Also, subjects were asked to refrain from participating in any other strenuous activities for the duration of the study. This was confirmed by asking the subjects on each visit and was further controlled by recording their entrance to the fitness center facilities by an electronic key card.

Anthropometric Assessment. Height was measured with a stadiometer to the nearest 0.5 cm (Seca, Chino, CA). Body mass, body fat, and muscle mass were measured with a multifrequency bioelectrical impedance analyzer (Seca mBCA 515; Seca). All body composition measurements were taken in the early morning hours (7–9 AM) in a fasted state. The subjects wore only light shorts and T-shirt. To ensure hydration and obtain valid measurements, the subjects were asked to drink at least 2 L of fluids the day before body composition assessment and to come to the laboratory at exactly the same time in both pre- and post-training measurements.

Cardiorespiratory Fitness Assessment. $\dot{V}O_2max$ and maximum heart rate (HRmax) were measured using an incremental running protocol on a level treadmill (h/p/cosmos pulsar 3p; HP Cosmos, Nussdorf-Traunstein, Germany). The initial speed was 8 $km \cdot h^{-1}$ and was increased every minute by 1 $km \cdot h^{-1}$ until exhaustion. Oxygen uptake was measured by a breath-by-breath analyzer (Quark CPET; Cosmed, Rome, Italy). The respiratory compensation (RC) point, corresponding to the second ventilatory threshold, was determined based on changes in minute ventilation (VE), $\dot{V}O_2$, and $\dot{V}CO_2$, according to Wasserman (44). Heart rate (HR) was continuously monitored using a Polar heart rate monitor (H10 Heart Rate sensor, Kempele, Finland). All subjects achieved a true $\dot{V}O_2max$ as they met the criteria set by ACSM (2).

Isokinetic Strength Assessment. Isokinetic leg strength of knee extensors and knee flexors was measured in an isokinetic dynamometer (HumacNorm, model 770; CSMI Humac Norm, Stoughton, MA). Subjects were seated and secured to the apparatus with chest and thigh straps. The torso was kept upright with the back of the seat vertical. The dynamometer axis was adjusted so that the center of motion of the lever arm was aligned with the flexion-extension axis of the knee joint. The range of motion was kept between 0° and 90°. Subjects performed 5 maximal concentric extensions and flexions with an angular velocity of $60° \cdot s^{-1}$ under strong verbal encouragement. This angular velocity is commonly used for isokinetic strength assessment of the knee extensors and flexors, as it provides valid and reliable results (3). Peak torque was determined as the highest value of knee extension and knee flexion obtained during the test.

Vertical Jump Performance. The subjects performed squat jumps (SJs), hands kept firmly on the waist, and countermovement jumps with free arms (CMJs). Jump height was calculated from flight time using the OptoJump Next device (Microgate, Bolzano,

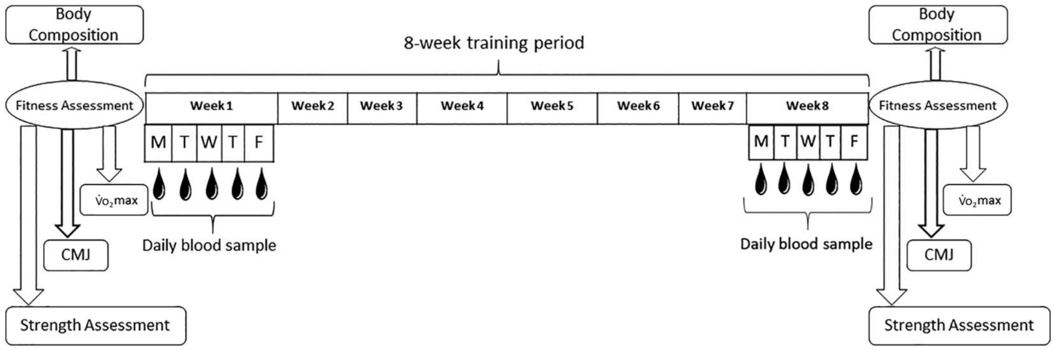

Figure 1. Experimental protocol of the study. CMJ = countermovement jump; $\dot{V}O_2max$ = maximal oxygen uptake.

Italy). Three efforts were allowed for each jump with a 1-minute rest between jumps, and the best effort was recorded.

Upper Body Strength. Bench press was used to evaluate upper-body strength. Because all subjects had previous experience with bench press, an estimate of their 1RM was used to set the weight for the initial sets of the test. After a warm-up with light weights, the subjects were asked to perform 10 repetitions at 50% of the estimated 1RM and then 5 repetitions at 75% and 3 repetitions at 85%. Then, the weight was increased by 2.5 or 5 kg sequentially, with the subjects performing one press at each weight until true 1RM was achieved. A 4-minute rest period was kept between sets and single efforts.

Muscle Endurance. Muscle endurance was assessed for the upper body and the abdominal muscles. The former was assessed by bench press at 65% 1RM: After 10 minutes of recovery after the measurement of their 1RM, the subjects were asked to perform as many repetitions as possible at 65% 1RM with correct technique. The test was terminated when the subjects could not lift the bar or when their back was not kept on the bench. Muscle endurance of the abdominal muscles was assessed by the 1-minute sit-up test. The subjects were asked to perform as many sit-ups as possible in 1 minute in a supine position, with knees bent at 90°, feet kept firmly on the ground by an assistant, and arms crossed at the chest with the elbows kept on the abdomen. A repetition was accepted when the elbows touched the thighs.

High-Intensity Functional Training Protocol. All subjects executed the HIFT protocol on Mondays, Wednesdays, and Fridays, at 5 PM. Before the start of training, all subjects were familiarized with the training protocol and the equipment used in 2–3 familiarization sessions.

In each training session, upon arrival at the exercise facility, a 10-minute standardized warm-up was conducted, consisting of functional exercises, small leaps, dynamic stretching, and short sprints. After warm-up, the subjects completed the HIFT protocol, which included 9 30-second exercises: upright and sumo squat (65% 1RM), sit-ups holding a 3-kg medicine ball, clean and press (65% 1RM), box jumps (45-cm box) chest press using suspension straps (TRX), wall-ball throws using a 4-kg medicine ball, burpees, sledgehammer exercise (3–5 kg hammer), and repeated all-out 10-m sprints. The work-to rest ratio was 2:1, i.e., 30 seconds of work was followed by 15 seconds of recovery, during which the subjects moved to the next exercise. Each session included 4 rounds of the 9 exercises, with a 2-minute break between rounds 2 and 3. Performance improvement in conducting the exercises was assessed by recording the total number of repetitions executed during each exercise (30 seconds) at rounds 1 and 4, in the first training session of week 1 and 8.

The determination of the load (65% 1RM) to be used during the HIFT program for sumo squat and clean and jerk was done during the preliminary testing period, based on the subjects' predicted 1RM. During a separate session, the subjects were asked to perform multiple (2–4) sets of 8 repetitions, with 4 minutes of rest, until the maximum weight that could be lifted for 8 repetitions with correct technique was achieved. Then, 1RM was estimated from the load of 8RM based on the relevant literature (29), and the final 65% 1RM load was calculated.

Heart Rate Recording. Heart rate was continuously monitored during each training session as an index of internal load using telemetric sensors and software (H7 Polar Team version 1.2). Peak and average HR, as well as the total time during which HR was at or above 90% of maximal HR (T90), were recorded in each session.

Biochemical Measurements. During the first and last weeks of training, 5 ml of venous blood was taken from an arm vein in the morning of each weekday (Monday to Friday) between 7:30 and 9:30 AM in the fasted state for the determination of CRP and CK. During this time, a registered nurse was on site to perform the blood sampling. As the subjects entered the laboratory, they were allowed to sit comfortably for 20 minutes, before the nurse performed the venous puncture. The blood samples were dispensed in plain tubes and were left to clot. Then, the samples were centrifuged at 4,000 rpm for 8 minutes, and serum was collected in Eppendorf tubes. All blood analyses were performed on the sampling day. C-reactive protein was determined using an immunoturbidimetric test, and CK activity was determined using a kinetic UV test, both in a Beckman Coulter AU480 analyzer (Atlanta, GA) with commercially available kits.

Statistical Analyses

All statistical analyses were performed using SPSS for Windows, v.23.0 (IBM, Armonk, NY). Anthropometric and performance variables before and after training were compared using the paired Student *t*-test. Cohen's *d* was used to determine effect sizes for pair-wise comparisons. Effect size was considered small if between 0.2 and 0.49, medium if between 0.5 and 0.79, and large if 0.8 or higher (11). A two-way (2 × 5) repeated-measures analysis of variance (ANOVA) (week [first vs. eighth] × day [Monday to Friday]) was used to analyze the CK and CRP values. Also, a two-way ANOVA (week [first vs. eighth] × round [1 and 4]) was used to analyze performance during the HIFT sessions. When a significant main effect or interaction was found, the Tukey post-hoc test was used to locate significant differences. Partial eta-squared (η^2) values were used to estimate effect size in factorial ANOVA. Partial η^2 was considered small if between 0.01 and 0.059, moderate if between 0.06 and 0.137, and large if 0.138 or higher (11). Statistical significance was accepted at $p \leq 0.05$.

Results

All subjects completed the 8-week HIFT training period without any injuries.

Body Composition

Body mass, BMI, fat-free mass, and muscle mass did not change significantly after 8 weeks of HIFT (Table 1). However, body fat decreased by 0.64 ± 1.01 kg ($p = 0.041$, $d = 0.14$).

Cardiorespiratory Fitness

After the 8-week training program, $\dot{V}O_2$max increased by 1.9 ± 2.2 ml·kg^{-1}·min^{-1} (4.6%; $p = 0.009$, $d = 0.24$), maximum aerobic speed increased by 0.6 ± 0.8 km·h^{-1} (5.2%; $p = 0.014$, $d = 0.24$), and HR at RC decreased by 3 ± 5 b·min^{-1} (1.7%; $p = 0.045$, $d = 0.26$). Speed at RC tended to increase by 0.4 ± 0.7 km·h^{-1} ($p = 0.054$, $d = 0.22$). HRmax was 185 ± 10 b·min^{-1} and remained unchanged after training (Table 2).

Muscle Strength, Muscle Endurance, and Vertical Jump

Maximal strength in bench press increased by 4.5 ± 3.8 kg (8.9%, $p = 0.001$, $d = 0.20$). Squat jump improved by 3.0 ± 2.5 cm (10.7%, $p = 0.050$, $d = 0.41$) and CMJ by 2.6 ± 1.5 cm (7.9%, $p = 0.001$, $d = 0.30$). However, peak torque during knee extension ($p = 0.475$) and flexion ($p = 0.166$) showed no significant changes (Figure 2).

After the 8-week training program, there were large improvements in muscle endurance. The number of bench press repetitions at 65% 1RM increased by 4 ± 5 repetitions (21.0%, $p = 0.03$, $d = 0.92$), and the number of sit-ups in 1 minute increased by 6 ± 4 repetitions (15.0%, $p = 0.001$, $d = 0.73$, Figure 3).

Performance during the High-Intensity Functional Training Sessions

High-intensity functional training for 8 weeks resulted in an increase in the number of repetitions performed during the first and fourth rounds for 5 and 6, respectively, of the 9 exercises performed, as presented in detail in Figure 4. The only exercises in which performance was unaffected by training were the clean and press, wall ball throws, and hammer. Performance in all other exercises increased by 18–29%.

Table 1
Body composition data before and after 8 weeks of HIFT.

	Baseline	After 8 weeks	Change (%)	p
Body mass (kg)	65.3 ± 13.1	64.7 ± 13.0	−0.1	0.191
BMI (kg·m^{-2})	24.0 ± 2.9	23.7 ± 2.9	−1.3	0.116
Body fat mass (kg)	15.0 ± 4.5	14.4 ± 4.3	−3.7	**0.041**
Muscle mass (kg)	23.6 ± 7.0	23.4 ± 6.9	−0.9	0.128
Fat-free mass (kg)	50.0 ± 12.4	50.1 ± 12.2	0.07	0.825

Bold entries = significance $p < 0.05$.

Heart Rate Responses During High-Intensity Functional Training

During the eighth week, average HR during training showed a decrease of approximately 2.9% ($p = 0.004$, $d = 0.65$), whereas peak HR ($p = 0.895$), % HRmax ($p = 0.904$), and T90 ($p = 0.150$) remained unchanged compared with week 1 (Figure 5).

Biochemical Parameters

No significant week × day interaction was found for CK ($p = 0.452$, $\eta^2 = 0.068$). A significant main effect was found for the day factor ($p = 0.008$, $\eta^2 = 0.243$), and post hoc comparisons showed that CK was higher in the morning after the first HIFT session of the week, compared with Friday ($p = 0.043$, $d = 0.44$), and tended to be higher compared with Wednesday ($p = 0.069$, $d = 0.42$) and Monday ($p = 0.077$, $d = 0.38$). Thursday's CK values (morning after the second HIFT session of the week) were similar to Tuesdays' values ($p = 0.98$) (Figure 6A). Furthermore, there was a significant main effect of week ($p = 0.027$, $\eta^2 = 0.347$), indicating that the average CK during the eighth week was 32% lower compared with the first week (160 vs. 235 U·L^{-1}, Figure 6A).

No significant week × day interaction was found for CRP ($p = 0.425$). There were also no significant main effects of day ($p = 0.310$) or week ($p = 0.225$), indicating that CRP was not affected by HIFT in the short or long term (Figure 6B).

Discussion

This study showed that HIFT, performed for 8 weeks, has a considerable impact on cardiorespiratory fitness, muscle endurance, maximum upper-body strength, and vertical jump without inducing muscle damage or inflammation. These results suggest that HIFT is not only a highly effective but also a safe approach for physically active persons who aim to improve several aspects of their physical fitness, including endurance, strength, and power components of the lower and upper body, by exercising for only 30 minutes per session, 3 times a week.

It is well known that endurance training programs and HIIT regimes of cycling, running, or rowing are highly effective forms of exercise in terms of improving cardiorespiratory fitness (18). However, there are only a few studies examining the effects of functional strength training exercises performed in a circuit manner (i.e., HIFT) on $\dot{V}O_2$max (5,33). In this study, we showed that HIFT of this form may impose a high load on the cardiorespiratory system because the peak HR attained was 95% of HRmax and the average HR was above 90% of HRmax for about 50–65% of the duration of training sessions (Figure 5). Interestingly, this high cardiorespiratory load was attained by repeating strength, speed, and power exercises, such as jumping, weightlifting, and 10-m sprints, for 30 seconds, with a short recovery interval (work-to-rest ratio of 2 to 1). Thus, these findings show that HIFT may be considered as a promising method in terms of improving cardiovascular fitness because it improves

Table 2
Cardiorespiratory fitness parameters before and after 8 weeks of HIFT.*

	Baseline	After 8 weeks	Change, %	*p*
$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	44.2 ± 8.2	46.1 ± 8.1	4.3	**0.009**
HRmax (b·min^{-1})	185 ± 10	185 ± 10	0	0.529
Maximum aerobic speed (km·h^{-1})	13.6 ± 2.7	14.2 ± 2.5	4.5	**0.014**
Speed at RC (km·h^{-1})	10.8 ± 1.9	11.2 ± 1.8	3.6	0.054
HR at RC (b·min^{-1})	171 ± 13	168 ± 11	−1.7	**0.045**

*HIFT = high-intensity functional training; $\dot{V}O_2max$ = maximal oxygen uptake, HR = heart rate, HRmax = maximum heart rate, RC = respiratory compensation point; Bold entries = significance $p < 0.05$.

both $\dot{V}O_2max$ and ventilatory threshold, as assessed by the RC point (Table 2).

A significant reduction in body fat was found in this study (Table 1). A similar finding has only been reported in one previous HIFT study lasting 16 weeks (14), whereas other studies have reported either no change in body fat (5,15) or a decrease in body fat percentage due to an increase of lean mass (31). Thus, the present HIFT protocol seems to be effective in terms of improving body composition after only 8 weeks of HIFT in both absolute (kg of fat) and relative terms (% body fat). The physiological mechanism of body fat loss is beyond the scope of this study, but previous studies have suggested that during and in the few hours after a HIIT session, fat oxidation is increased (39,43). Furthermore, a recent study on HIFT reported increased growth hormone releases after exercise, which may increase the metabolic rate and fat oxidation (6).

In addition to the positive effects on cardiovascular fitness and body composition, HIFT resulted in considerable increases in upper-body muscle strength (by 8.9%), lower-body power (7.9%, Figure 2), and even more in muscular endurance of the abdominal muscles and upper body (by 15–21%, Figure 3). The greater improvement in local muscular endurance, compared with strength and power, may be due to increased ability to perform more repetitions within the available time (30 seconds) in most exercises, as indicated in Figure 3, which shows an 18–29% increase in repetitions performed after 8 weeks of training. Thus, the total number of executed repetitions in each exercise probably increased progressively during training, and this increased training load may have had an impact on local muscular endurance. The higher local muscular endurance after HIFT may be underpinned by peripheral adaptations, increasing muscle oxidative capacity, such as increases in muscle capillary density and mitochondrial content, as well as improved mitochondrial enzyme function (17,35).

Despite the increase in 1RM in bench press and the use of loads that would induce muscle hypertrophy during training (e.g., sumo squat and clean and press at 65% of 1RM) (25,34), no change in muscle mass was observed in this study (Table 1). This may be due to the concurrent training effect, where hypertrophic signals in the muscle, such as the mTOR pathway, are inhibited by an increase in AMPK pathway signaling (10). Thus, the increases in 1RM during bench press may be attributed to neural factors (19). In addition, the loads used in this study may have not been adequate to induce hypertrophy, as the subjects had previous experience with resistance exercise (1). Notably, similar to the strength improvements, the improvement of vertical jump performance may also be attributed to neural adaptations, such as increased muscle activation and coordination (4). The lack of improvement in peak isokinetic torque at a speed of 60°·s^{-1} for both the quadriceps and hamstrings may imply that the exercises incorporated in the present HIFT program did not address those muscles considerably or that the monoarticular testing of the knee muscles does not reflect the multijoint adaptations resulting from functional training.

A main aim of this study was to examine changes in muscle damage and inflammation indices during the first and eighth weeks of the training period. To the best of our knowledge, the effects of HIFT programs on biochemical and hormonal indices remain poorly investigated. In a recent study (27), a HIFT session increased both circulating testosterone and cortisol concentrations on the day after the exercise session. In addition, 2 consecutive HIFT sessions increased inflammatory cytokines, such as

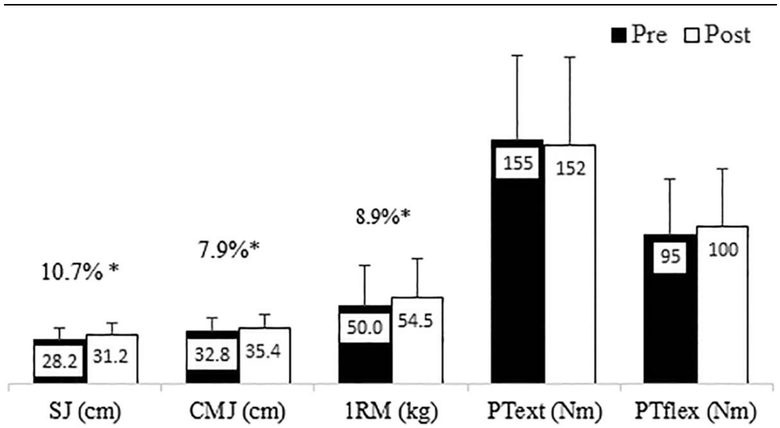

Figure 2. Squat jump (SJ), countermovement jump (CMJ), maximum bench press strength (1RM), and peak isokinetic torque for knee extension (PText), and flexion (PTflex) measured at an angular velocity of 60°·s^{-1}, before (pre) and after (post) 8 weeks of HIFT training. Percentages represent changes between pre and post values. *$p < 0.05$ from pre-training.

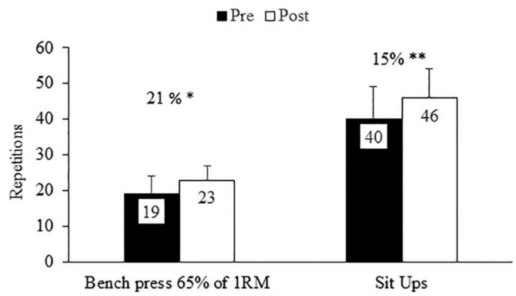

Figure 3. Number of repetitions performed to exhaustion in the bench press exercise with a load of 65% 1RM and in the 1-minute sit up exercise, before (pre) and after (post) training. *SD* bars are also shown. Percentages represent changes between prevalues and postvalues after 8 weeks of HIFT. *$p = 0.030$, **$p < 0.001$ from pre-training.

IL-6, on the day after exercise (41). The studies above have investigated only the acute effects of HIFT on the hormonal milieu and inflammatory markers. However, this study was the first to examine changes in muscle damage and inflammation indices for 5 consecutive days both at the beginning and end of a period of HIFT. It was expected that the high-intensity nature of this program, including plyometric, sprinting, and strength exercises, would cause muscle damage and inflammation (28,37,42).

However, the results showed a moderate rise in CK only in the morning after the first HIFT session (i.e., ~14 hours later), with CK returning to baseline in less than 48 hours after each session. Notably, although the increase in CK was statistically significant, the magnitude of change of CK did not considerably exceed the upper limit of normal values (30). Also, there was no added effect of multiple workouts during the week on CK, but it may be argued that each training session caused a small increase in CK the day after (i.e., Monday's session increased CK activity on Tuesday morning), which returned to pre-exercise levels on Wednesday morning (Figure 6). This is possibly due to the training status of our subjects, who were accustomed to this type of exercise, and contrasts with what is observed after unaccustomed concentric or plyometric resistance exercise in untrained subjects (23) or elite male and female players after a soccer match (36), where CK peaked 24 hours post-exercise and remained elevated for 48–72 hours. Therefore, this HIFT program seems to have only a minimal and transient effect on CK activity, implying a low degree of muscle damage, possibly due to its duration and content, as well as the training status of the subjects who had been training with resistance and cardio exercise in the gym 3–4 times per week for more than 6 months before the study. In addition, during the eighth week of the training period, CK response after training sessions was decreased compared with week 1, showing the adaptability of the muscles to that HIFT training regime, according to the repeated bout effect (8,42).

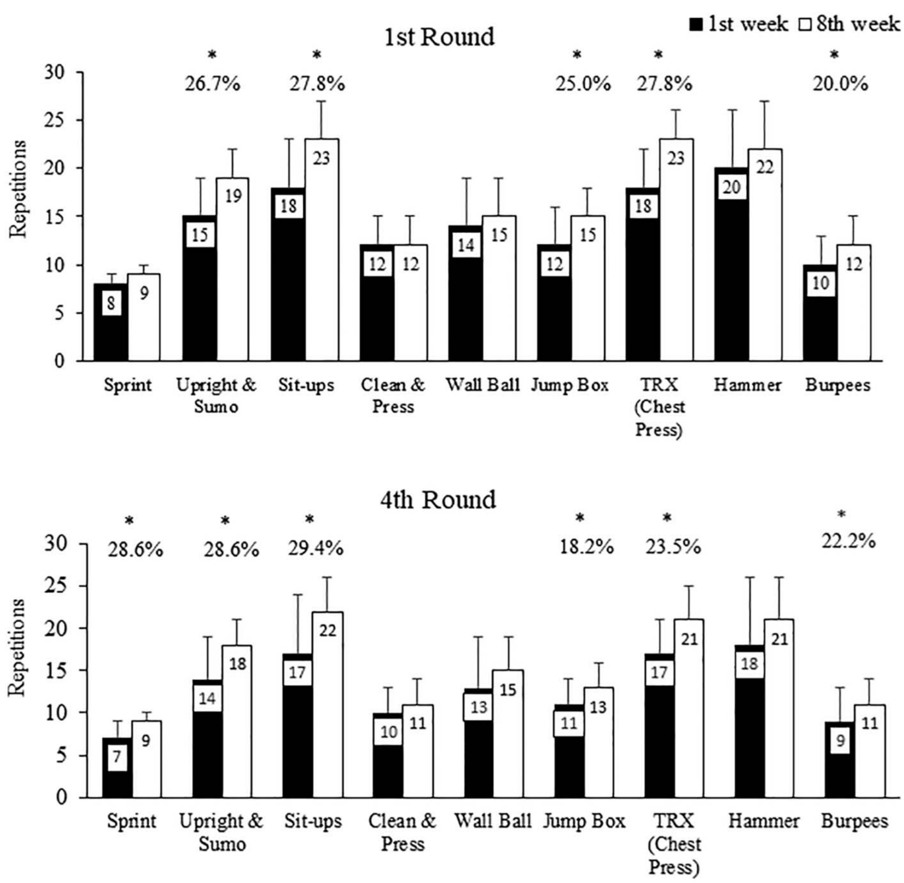

Figure 4. Number of repetitions (mean and *SD*) performed in each of the 9 exercises performed at the first and fourth rounds of the HIFT protocol during the first and eighth weeks of training. Percentages represent statistically significant changes ($p \leq 0.010$) between the first and eighth weeks of HIFT.

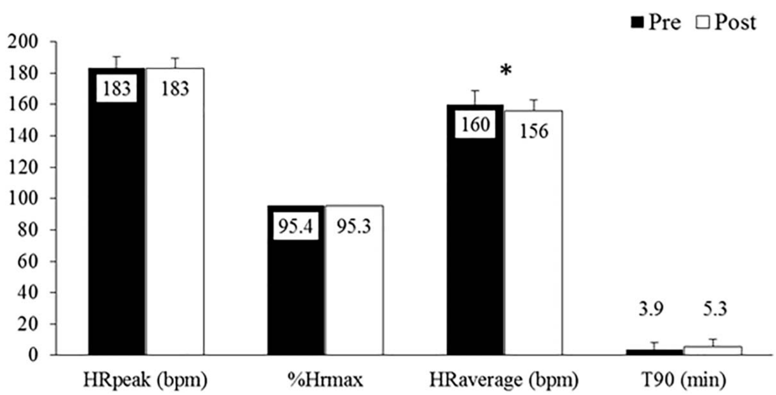

Figure 5. Heart rate responses during the HIFT protocol during the first and eighth weeks of training. HRpeak = peak heart rate during training; %HRmax = HRpeak expressed as a percentage of maximum heart rate (HRmax); HRaverage = average heart rate during training; T90 = time during which heart rate was above 90% of HRmax. *$p < 0.05$, significantly different from pre-training.

C-reactive protein, an index of inflammation, was not increased at any time during the first and last weeks of the HIFT program (Figure 6). After intense exercise, microtrauma in the muscles may lead to a systemic inflammatory response (7). However, it seems that the physiological and neuromuscular loading during the HIFT program was not high enough to cause a CRP rise (24). It has been reported that the acute-phase inflammatory response is proportional to muscle injury, and therefore, changes in CRP may follow the CK response (22). Thus, in this study, the lack of a CPR response suggests lack of significant inflammatory responses due to the low degree of muscle damage, as indicated by the moderate increase in CK (22,24).

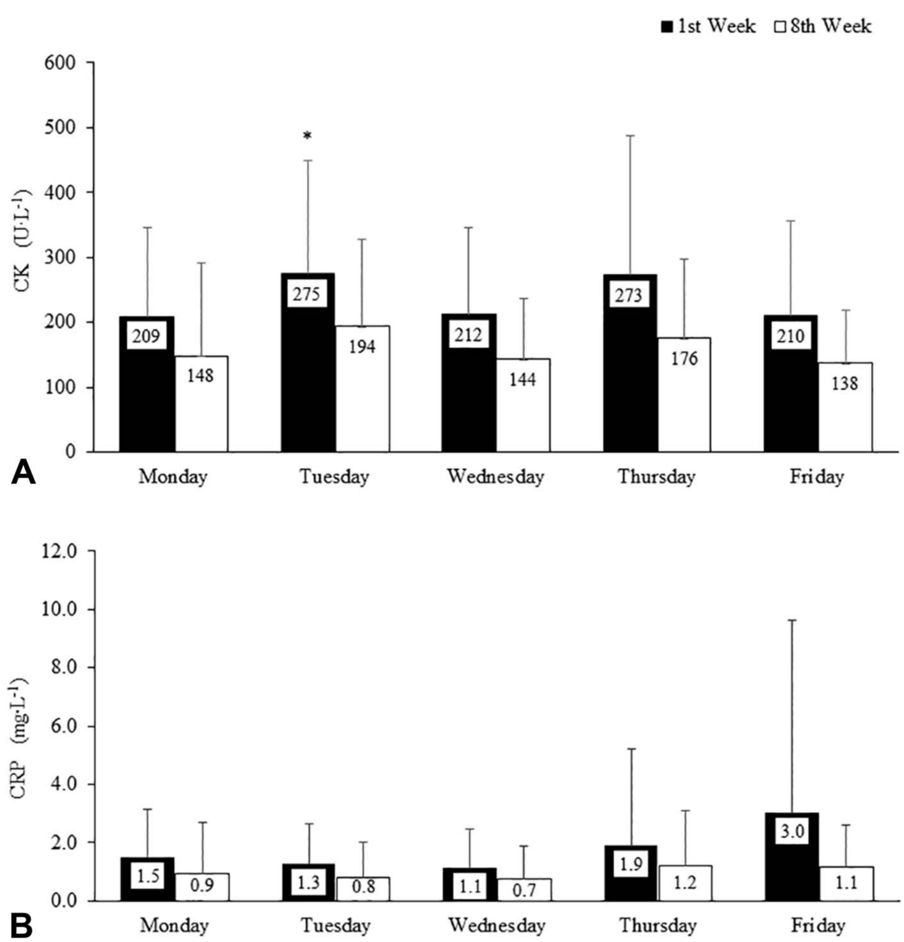

Figure 6. Serum creatine kinase (CK, A) and C-reactive protein (CRP, B) during the weekdays of the first and eighth weeks of HIFT. *$p < 0.05$ significantly different from Friday (main effect for days).

The lack of a control group may be considered as a limitation of this study. However, it was not possible to find individuals of comparable fitness with our subjects, who would abstain from exercise for 8 weeks, as one of the selection criteria was the practice of gym-based resistance and cardio training for more than 6 months before the start of the study.

In conclusion, the findings of this study show that an 8-week HIFT, group-based program can effectively improve various physical fitness and body composition parameters in healthy adults. The current program was well tolerated by the subjects, as it did not result in any muscle injury and was accompanied by a small increase of the indirect muscle damage index CK and the inflammatory index CRP. Therefore, this HIFT program could be deemed suitable and effective in increasing overall fitness for the general healthy population.

Practical Applications

This study provides both sports scientists and fitness group leaders with an effective HIFT regime, suitable for eliciting favorable fitness changes over 8 weeks without any adverse responses, such as muscle damage or inflammation. As HIFT becomes increasingly popular in fitness centers, with many individuals wishing to improve overall fitness with minimal time investment, protocols similar to that presented in this study may be considered as safe and effective options.

Acknowledgments

The authors thank the volunteers who participated in this study and the staff of UFIT Gym for their valuable help. The authors declare that they have no conflict of interest. The results of this study do not constitute endorsement of the product by the authors or the NSCA.

References

1. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
2. Arena, R. Health-related physical fitness testing and interpretation. In: *ACSM's Guidelines for Exercise Testing and Prescription* (9th Edition): LS Pescatello, R Arena, D Riebe and PD Thompson, eds. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins, 2014. pp. 60–114.
3. Baltzopoulos V, Brodie DAJSM. Isokinetic dynamometry. *Sports Med* 8: 101–116, 1989.
4. Bobbert MF, van Ingen Schenau GJ. Coordination in vertical jumping. *J Biomech* 21: 249–262, 1988.
5. Brisebois MF, Rigby BR, Nichols DL. Physiological and fitness adaptations after eight weeks of high-intensity functional training in physically inactive adults. *Sports (Basel)* 6: E146, 2018.
6. Cadegiani FA, Kater CE, Gazola M. Clinical and biochemical characteristics of high-intensity functional training (HIFT) and overtraining syndrome: Findings from the EROS study (the EROS-HIFT). *J Sports Sci* 37: 1296–1307, 2019.
7. Chatzinikolaou A, Fatouros IG, Gourgoulis V, et al. Time course of changes in performance and inflammatory responses after acute plyometric exercise. *J Strength Cond Res* 24: 1389–1398, 2010.
8. Chen TC, Chen HL, Pearce AJ, Nosaka K. Attenuation of eccentric exercise-induced muscle damage by preconditioning exercises. *Med Sci Sports Exerc* 44: 2090–2098, 2012.
9. Clarkson PM, Hubal MJ. Exercise-induced muscle damage in humans. *Am J Phys Med Rehabil* 81: S52–S69, 2002.
10. Coffey VG, Hawley JA. Concurrent exercise training: Do opposites distract? *J Physiol* 595: 2883–2896, 2017.
11. Cohen J. The t-test for means. In: *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum Associates, 1988. pp. 19–74.
12. Falk Neto JH, Kennedy MD. The multimodal nature of high-intensity functional training: Potential applications to improve sport performance. *Sports (Basel)* 7: pii E33, 2019.
13. Feito Y, Heinrich KM, Butcher SJ, Poston WSC. High-intensity functional training (HIFT): Definition and research implications for improved fitness. *Sports (Basel)* 6: pii E76, 2018.
14. Feito Y, Hoffstetter W, Serafini P, Mangine G. Changes in body composition, bone metabolism, strength, and skill-specific performance resulting from 16-weeks of HIFT. *PLoS One* 13: e0198324, 2018.
15. Feito Y, Patel P, Sal Redondo A, Heinrich KM. Effects of eight weeks of high intensity functional training on glucose control and body composition among overweight and obese adults. *Sports (Basel)* 7: pii E51, 2019.
16. Fisher J, Sales A, Carlson L, Steele J. A comparison of the motivational factors between CrossFit subjects and other resistance exercise modalities: A pilot study. *J Sports Med Phys Fitness* 57: 1227–1234, 2017.
17. Fisher J, Steele J. Questioning the resistance/aerobic training dichotomy: A commentary on physiological adaptations determined by effort rather than exercise modality. *J Hum Kinet* 44: 137–142, 2014.
18. Gibala MJ, Little JP, MacDonald MJ, Hawley JA. Physiological adaptations to low-volume, high-intensity interval training in health and disease. *J Physiol* 590: 1077–1084, 2012.
19. Häkkinen K, Alen M, Komi PV. Changes in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand* 125: 573–585, 1985.
20. Heinrich KM, Patel PM, O'Neal JL, Heinrich BS. High-intensity compared to moderate-intensity training for exercise initiation, enjoyment, adherence, and intentions: An intervention study. *BMC Public Health* 14: 789, 2014.
21. Heinrich KM, Spencer V, Fehl N, Poston WS. Mission essential fitness: Comparison of functional circuit training to traditional army physical training for active duty military. *Mil Med* 177: 1125–1130, 2012.
22. Isaacs AW, Macaluso F, Smith C, Myburgh KH. C-reactive protein is elevated only in high creatine kinase responders to muscle damaging exercise. *Front Physiol* 10: 86, 2019.
23. Jamurtas AZ, Fatouros IG, Buckenmeyer P, et al. Effects of plyometric exercise on muscle soreness and plasma creatine kinase levels and its comparison with eccentric and concentric exercise. *J Strength Cond Res* 14: 68–74, 2000.
24. Kasapis C, Thompson PD. The effects of physical activity on serum C-reactive protein and inflammatory markers: A systematic review. *J Am Coll Cardiol* 45: 1563–1569, 2005.
25. Kraemer WJ, Adams K, Cafarelli E, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 34: 364–380, 2002.
26. MacInnis MJ, Gibala MJ. Physiological adaptations to interval training and the role of exercise intensity. *J Physiol* 595: 2915–2930, 2017.
27. Mangine GT, Van Dusseldorp TA, Feito Y, et al. Testosterone and cortisol responses to five high-intensity functional training competition workouts in recreationally active adults. *Sports (Basel)* 6: pii E62, 2018.
28. Minahan CL, Poke DP, Morrison J, Bellinger PM. Muscle damage and metabolic responses to repeated-sprint running with and without deceleration. *J Strength Cond Res* 34: 3423–3430, 2020.
29. Morales J, Sobonya S. Use of submaximal repetition tests for predicting 1-RM strength in class athletes. *J Strength Cond Res* 10: 186–189, 1996.
30. Mougios V. Reference intervals for serum creatine kinase in athletes. *Br J Sports Med* 41: 674–678, 2007.
31. Nieuwoudt S, Fealy CE, Foucher JA, et al. Functional high-intensity training improves pancreatic beta-cell function in adults with type 2 diabetes. *Am J Physiol Endocrinol Metab* 313: E314–E320, 2017.
32. Phillips T, Childs AC, Dreon DM, Phinney S, Leeuwenburgh C. A dietary supplement attenuates IL-6 and CRP after eccentric exercise in untrained men. *Med Sci Sports Exerc* 35: 2032–2037, 2003.
33. Roberts MA, O'Dea J, Boyce A, Mannix ET. Fitness levels of firefighter recruits before and after a supervised exercise training program. *J Strength Cond Res* 16: 271–277, 2002.
34. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, Sonmez GT. Effects of low- vs. high-load resistance training on muscle strength and

hypertrophy in well-trained men. *J Strength Cond Res* 29: 2954–2963, 2015.
35. Scott SN, Shepherd SO, Hopkins N, et al. Home-HIT improves muscle capillarisation and eNOS/NAD(P)Hoxidase protein ratio in obese individuals with elevated cardiovascular disease risk. *J Physiol* 597: 4203–4225, 2019.
36. Souglis AG, Papapanagiotou A, Bogdanis GC, et al. Comparison of inflammatory responses to a soccer match between elite male and female players. *J Strength Cond Res* 29: 1227–1233, 2015.
37. Spada TC, Silva J, Francisco LS, et al. High intensity resistance training causes muscle damage and increases biomarkers of acute kidney injury in healthy individuals. *PLoS One* 13: e0205791, 2018.
38. Stavrinou PS, Bogdanis GC, Giannaki CD, Terzis G, Hadjicharalambous M. High-intensity interval training frequency: Cardiometabolic effects and quality of life. *Int J Sports Med* 39: 210–217, 2018.
39. Talanian JL, Galloway SD, Heigenhauser GJ, Bonen A, Spriet LL. Two weeks of high-intensity aerobic interval training increases the capacity for fat oxidation during exercise in women. *J Appl Physiol (1985)* 102: 1439–1447, 2007.
40. Thompson WR. Worldwide survey of fitness trends 2019. *ACSM's Health Fit J* 22: 10–17, 2018.
41. Tibana RA, de Almeida LM, Frade de Sousa NM, et al. Two consecutive days of crossfit training affects pro and anti-inflammatory cytokines and osteoprotegerin without impairments in muscle power. *Front Physiol* 7: 260, 2016.
42. Tofas T, Jamurtas AZ, Fatouros I, et al. Plyometric exercise increases serum indices of muscle damage and collagen breakdown. *J Strength Cond Res* 22: 490–496, 2008.
43. Tremblay A, Simoneau JA, Bouchard C. Impact of exercise intensity on body fatness and skeletal muscle metabolism. *Metabolism* 43: 814–818, 1994.
44. Wasserman K. The anaerobic threshold measurement in exercise testing. *Clin Chest Med* 5: 77–88, 1984.