Original Article

Physiological profile of high intensity functional training athletes

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ABSTRACT

Introduction: High intensity functional trainings (HIFT) are among the most common and popular training modalities. The aim of the present study was to examine the physiological characteristics of a group of HIFT competitive athletes both in a laboratory and field setting. Methods: Twenty HIFT athletes, 10 men (29 ± 5.3 years) and 10 women (30 ± 3.2 years), were evaluated in the laboratory for anthropometric characteristics, VO_{2peak}, lactate threshold, maximal anaerobic power, maximal voluntary isometric and isokinetic strength, and muscle power during a countermovement jump. Athletes were also monitored in the field by measuring VO_2 and lactate during a training session. Results: HIFT competitive athletes reached high levels in VO_{2peak} (52.9 ± 5.67 ml·kg-1·min-1 in men; 52.4 ± 6.17 ml·kg-1·min-1 in women), VO_2 at lactate threshold (79.7% of VO_{2peak} in men; 74.5% of VO_{2peak} in women), maximal anaerobic power (7.6 ± 1.32 W·kg-1 in men; 5.0 ± 1.13 W·kg-1 in women; $p < .05$), maximal voluntary knee extension isometric strength (11.7 ± 1.43 N·kg-1 in men; 9.5 ± 2.25 N·kg-1 in women; $p < .05$) and isokinetic strength (281.4 ± 31.56 N·kg-1 in men; 243.1 ± 44.13 N·kg-1 in women; $p < .05$), and muscle power during a countermovement jump (54 ± 5.9 W·kg-1 in men; 40 ± 4.8 W·kg-1 in women; $p < .05$). VO_{2peak} during the on-field training session (50.6 ± 3.82 ml·kg-1·min-1 in men; 51.9 ± 5.76 ml·kg-1·min-1 in women) and lactate production (10.4 ± 0.69 mmol·l-1 in men; 9.7 ± 0.96 mmol·l-1 in women) revealed the high intensity nature of HIFT. Conclusions: Overall, HIFT athletes show exceptional performances in physiological components that are key to many different sports. The lack of specialization in exclusively one domain of physical fitness reveals the comprehensive nature of this training methodology.

Keywords: Physical fitness; CrossFit; General preparedness programs; Sports performance; Functional exercise.

Cite this article as:
Adami, P.E., Rocchi, J.E., Melke, N., & Macaluso, A. (2020). Physiological profile of high intensity functional training athletes. *Journal of Human Sport and Exercise*, *in press*. doi:https://doi.org/10.14198/jhse.2021.163.16

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Submitted for publication February 25, 2020
Accepted for publication May 04, 2020
Published *in press* May 13, 2020
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2021.163.16

INTRODUCTION

High intensity functional trainings (HIFT) represent a recent development of high intensity trainings (HIT), that have emerged as effective training alternatives to improve fitness when compared to traditional circuit training. High intensity trainings are among the top 3 worldwide fitness trends since 2013, according to the American College of Sports Medicine (ACSM) annual survey (Thompson, 2013, 2018) and HIFT were indicated as the reason why HIT workouts were ranked so high.

Although HIT and HIFT share a common training strategy, that is “high intensity”, they significantly differ in the physiological responses and adaptations prompted. HIT, typically adopts unimodal protocols (e.g. rowing, running, cycling, arm-cranking) (Adami et al., 2015), while HIFT are multimodal and “functional”. Functional movements are multi-joint movements, involving large segments of the body and prompting complex motor recruitment patterns, on multiple planes (Heinrich, Patel, O'Neal, & Heinrich, 2014). The objective of these training programs is to improve the physical performance in multiple fitness domains, i.e. cardiovascular/respiratory endurance, anaerobic power, muscle strength, power, flexibility, speed, coordination, agility, balance and accuracy. An average HIFT incorporates elements of Olympic weightlifting and powerlifting, gymnastics, plyometrics and calisthenics exercises. They are characterized by high intensity exercises designed to emulate activities of daily living (ADL) and active recovery phases between sets, ensuring a continuous high oxygen consumption, with no real resting moments during the entire workout. Recovery in HIFT is obtained by changes in the types of exercises performed, representing an additional stimulus to the breadth and depth of the elicited adaptations. The adoption of these exercises in circuit or interval format, at high intensity, represents a great stimulus to improve muscle strength and power, and induce cardiovascular, aerobic and anaerobic adaptations (Alcaraz, Sanchez-Lorente, & Blazevich, 2008). One of the keys to success of HIFT is represented by self-selected intensity levels that participants can establish each time. This aspect dramatically increases adherence and enjoyment (Heinrich et al., 2014).

Although several researches have investigated some of the physiological features of HIFT athletes (Fernandez-Fernandez, Sabido-Solana, Moya, Sarabia, & Moya, 2015; Tibana, de Sousa, Prestes, & Voltarelli, 2018), to the best of the authors knowledge, there is no comprehensive physiological assessment of this population in the current literature. Therefore, the aim of the present study was to examine the physiological characteristics of a group of HIFT competitive athletes both in field and laboratory settings. We hypothesized that the high intensity nature of HIFT, as revealed by the high oxygen consumption and lactate production during an on-field monitored training session, is accompanied by adaptations to multiple physical fitness components, i.e. aerobic fitness, anaerobic power, muscle strength and power.

METHODS

Study population

A group of 10 male and 10 female HIFT competitive athletes were selected. Athletes were aged 18 to 40 years (mean 29 ± 5.3 years), practiced HIFT for at least 3 years and competed at national level for a minimum of 1 year, thus proving to be advanced and elite level athletes. All subjects were evaluated by a sports physician prior to their enrolment in the study, to confirm their health status and absence of cardiovascular risks. Written informed consent was obtained from each athlete undergoing the evaluation, compliant with Italian law and the University policies. The study design was approved by the Review Board of the University of Rome “Foro Italico” (CAR 13/2019). All clinical data assembled from athletes are maintained in a secured institutional database, compliant with GDPR regulations.

Anthropometric evaluation

Anthropometric evaluation (stature and body mass) including body composition assessment, was performed through skin-fold plicometry at seven sites, according to Jackson and Pollock (Jackson & Pollock, 1978; Jackson, Pollock, & Ward, 1980), by the same experienced researcher.

Maximal aerobic fitness assessment

All subjects underwent a ramp incremental maximal exercise test on a treadmill with continuous metabolic monitoring to measure their maximal aerobic fitness. Each subject was fitted with a heart rate (HR) monitor (Polar, Finland), and with a face mask linked to a portable metabolimeter (K4b2, COSMED, Italy). Oxygen uptake (VO_2) and carbon dioxide production (VCO2) were measured by means of a portable metabolimeter. HR was telemetrically transmitted and recorded in the K4 system. The system was calibrated prior to each test according to the manufacturer’s specifications. The test protocol adopted was previously described and validated in this type of athletes (Bellar, Hatchett, Judge, Breaux, & Marcus, 2015). Every two minutes, up until exhaustion, investigators asked participants to rate their overall exertion on a printed Borg 6-20 Rate of Perceived Exertion (RPE) scale (Borg, 1998). The test aimed at reaching individuals’ exhaustion as it has been explained extensively in the literature ("Clinical Exercise Testing", 2012).

Maximal anaerobic lactic power

The maximal anaerobic lactic power was assessed through a running based anaerobic sprint test (RAST) (Zacharogiannis, Paradisis, & Tziortzis, 2004). The test provides data on anaerobic power, such as peak power (PP), mean power (MP) and fatigue index (FI), that correspond to the Wingate mechanical power developed by the recruited muscular group (Queiroga et al., 2013). Before starting the test and at 1’, 3’, 5’ and 7’ post-test peripheral blood lactate concentration was measured using a Lactate Pro 2 analyser (KDK Array, Japan), from a 5 ml sample of capillary blood taken from the ear lobe, to determine the lactate peak concentrations ([LAC]PEAK) (Wasserman, Beaver, & Whipp, 1986).

Lower limb maximal voluntary isometric strength

Maximal voluntary isometric strength of the lower limbs was measured on leg extension and leg curl machines (Technogym Selection, Technogym, Forlì-Cesena, Italy) in a seated position with 90° of flexion at the hip and knee joints, as previously described by Menotti et al (Menotti et al., 2012). A rigid leg cuff was connected to a strain-gauge load cell (Muscle Lab Force Sensor, Ergotest technology AS, Porsgrunn, Norway) through a stiff steel rod. Subjects were carefully instructed to contract as fast and forceful as possible on a given signal from the test leader (Bemben, Clasey, & Massey, 1990). MVC was defined as the peak isometric torque (N·m) exerted within the entire contraction phase. MVC measurements were averaged for each leg from the three trials, interspersed by 1-min recovery each.

Upper limb maximal voluntary isometric strength (handgrip)

Handgrip strength was measured using a handgrip dynamometer (Baseline®, Hydraulic Hand Dynamometer, Fabrication Enterprises Inc., White Plains, NY, 10602, USA). According to previously described protocols (Mathiowetz et al., 1985), participants were instructed to exert their maximum strength and keep the grip for at least 5 seconds. Handgrip trials were performed three times per hand, alternating hands, with 1-min recovery between trials. The maximum grip strength was measured in kilograms (kg) and the average value of the three trials per hand, was considered for analysis.

Isokinetic lower limb strength

Isokinetic lower limb strength was measured on an Easytech Genu 3 isokinetic dynamometer (Easytech srl, Borgo San Lorenzo, FI, Italy). The dynamometer was calibrated according to the manufacturer instructions before each test. The test consisted of two trials of reciprocal knee extensions and flexions per leg, executed at 90°·s-1 and 180°·s-1 of angular speeds, respectively. The 90°·s-1 speed trial consisted of 4 contractions aimed at measuring maximal strength capacity both in extension and flexion, while the 180°·s-1 speed trial consisted of 20 contractions and aimed at assessing the muscular power (work) and the fatigue index (power decrease), as described by Stumbo et al. (Stumbo et al., 2001).

Maximal anaerobic alactic capacity

Athletes' maximal anaerobic alactic capacity was measured through a standardized both-legs counter-movement jump (CMJ) performed on a force platform (model 9281 B; KISTLER Instrument GmbH, Sindelfingen, Germany), as it has been previously described (Labanca et al., 2016; Macaluso, Young, Gibb, Rowe, & De Vito, 2003). The velocity was obtained from the time integration of the instantaneous acceleration, that is equal to the ratio of force to the participant's mass. The time course of the power developed was calculated from the product of the instantaneous force and corresponding velocity. The obtained maximal instantaneous peak power was then divided by the participants' body mass and reported in watts per kilogram. Each participant performed three jumps with a 1-min rest in between. The assessment was performed, in order to look at the relationship between muscle power and functional capacity (Macaluso & De Vito, 2004).

On-field monitored training session

Each athlete was evaluated during a HIFT training session. The test called "Nancy" included 5 rounds for time of 400 m run and 15 overhead squats with 42.5 kg for men and 30 kg for women. Athletes were fitted with the same K4b2 portable metabolimeter and HR monitor used for the maximal aerobic fitness assessment. The metabolimeter was calibrated prior each test and according to the manufacturer specifications. HR_{peak}, VO_{2peak}, VO_2 and HR at the anaerobic threshold were calculated afterwards using the COSMED CPET Software Suite (ver. 10.0, COSMED, Rome, Italy). Athletes were asked to perform at their best. Before starting the test, peripheral blood lactate concentration was measured in resting conditions, using a Lactate Pro 2 analyser (KDK Array, Japan), from a 5 ml sample of capillary blood taken from the ear lobe and repeated at the end of the test at 1', 3', 5' and 7' to determine the lactate peak concentrations ([LAC]PEAK) (Wasserman et al., 1986). RPE measurements were taken at the end of the session workout. Subjects had to give ratings corresponding to their perceived exertion with the same printed Borg 6-20 RPE scale used in the maximal aerobic fitness assessment (Borg, 1998).

Participants reported to the testing laboratory on three separate occasions. On the first visit (T1), eligible participants were advised of the purpose, risks, and benefits associated with the study. Athletes were then evaluated through anthropometric measurements, including body composition assessment. Upper and lower limb maximal isometric strength, countermovement vertical jump, lower limb muscular forces in dynamic conditions through the isokinetic machine and maximal aerobic fitness assessment. Participants returned to the Exercise Physiology Laboratory for the second visit (T2) to complete a running based anaerobic sprint test (RAST) on the field. The third visit (T3) was used to measure the oxygen consumption during the on-field monitored training session. On all occasions, participants were instructed to restrain from alcohol consumption for at least 24 hours, exercise for the previous 12 hours, and avoid consuming food or any beverage other than water for four hours prior to testing. All indoor tests were performed wearing light and comfortable clothing (e.g. shorts and t-shirt) as desired by the athlete, and in a standardized environment (e.g., temperature and humidity changes).

Statistical analysis

The study design was a retrospective cohort study of the physical features of a group of highly trained competitive HIFT athletes, recruited from several training centres in the city of Rome, Italy. Continuous data are expressed as mean ± SD. Gender differences were evaluated by paired-samples t-test. Simple Pearson's r correlations were used to determine the associations between on-field monitored training session performance data, and the physiological measures. For each of the dependent on-field monitored training session variables, a forward stepwise linear regression model was created using the significant correlative data. The probability of F used for variables to enter the model was less than or equal to .05, and to remove variables was greater than or equal to .10. Countermovement jump analysis of maximal power, optimal velocity and optimal force was performed using a custom MATLAB programme (MathWorks, Inc., Natick, MA, USA). Statistical analysis was performed using SPSS (version 22, SPSS Inc. Chicago IL, USA) and statistical significance was set at $p < .05$.

RESULTS

Anthropometric data

Athletes' age was 29 ± 5.3 (18–36) years in males and 30 ± 3.2 (26–36) in females. Mean measures of body mass, height and body surface area (BSA) were significantly greater for males than for females. Men had also a higher lean body mass (LBM) and less body fat than women. Body fat percentage was in the optimal range for both groups, based on gender, age and ethnicity criteria (Gallagher et al., 2000; Kelly, Wilson, & Heymsfield, 2009; Rodriguez, DiMarco, & Langley, 2009). Populations' anthropometric characteristics are presented in Table 1.

Table 1. Anthropometric characteristics.

	Women	**Men**	**p value**
Age (years)	30 ± 3.2	29 ± 5.3	.6
Height (cm)	165.1 ± 4.67	179.9 ± 4.38	< .05
Body mass (kg)	62.2 ± 5.68	83.4 ± 6.95	< .05
Fat Body Mass (kg)	12.3 ± 3.01	10.7± 2.32	.18
Fat Body Mass (%)	19.0 ± 3.75	12.7 ± 2.44	< .05
Lean Body Mass (kg)	49.9 ± 3.45	72.8 ± 5.75	< .05
BSA (m2)	1.67 ± 0.111	2.01 ± 0.106	< .05

Note: BSA, body surface area.

Maximal aerobic fitness assessment and on-field monitored training session

Values from the maximal incremental exercise test and on-field monitored training session (Nancy) are presented in Table 2. VO_{2peak} absolute values for treadmill and on-field monitored training session were significantly greater in men than in women. This analysis did not show a significant difference when values were normalized for body mass. No differences were present when analysing intra-gender variables between the maximal incremental test and on-field monitored training session. Overall variables analysis did not show any significant differences when comparing the two tests. Figure 1 shows the individual variability of VO_{2peak}/kg for both tests and Figure 2 a typical VO_2 and HR graph during an on-field monitored training session.

Table 2. Values of variables from VO$_{2peak}$ test and Field Test expressed in absolute (ml·min-1) terms and relative to body mass (ml·kg-1·min-1).

Treadmill test	**Women**	**Men**	**p value**
VO$_{2peak}$ (ml·min-1)	3256.7 ± 392.68	4413.7 ± 534.89	< .05
VO$_{2peak}$/kg (ml·kg-1·min-1)	52.4 ± 6.17	52.9 ± 5.67	.8
HRpeak (bpm)	180.2 ± 9.34	180.6 ± 6.31	.9
HRpeak % of HRmax	95.5 ± 5.12	95.0 ± 4.69	.8
HR@LT (bpm)	149.0 ± 10.36	147.9 ± 14.74	.8
VO$_2$@LT/kg (ml·kg-1·min-1)	39.2 ± 6.75	42.3 ± 7.63	.3
VO$_2$@LT % of VO$_{2peak}$	74.5 ± 7.23	79.7 ± 10.85	.2
RPE	18.3 ± 0.82	17.9 ± 1.66	.5
On-field monitored training session			
VO$_{2peak}$ (ml·min-1)	3219.4 ± 355.56	4224.0 ± 478.23	< .05
VO$_{2peak}$/kg (ml·kg-1·min-1)	51.9 ± 5.76	50.6 ± 3.82	.5
VO$_{2mean}$ (ml·min-1)	2830.0 ± 327.60	3747.9 ± 457.18	< .05
VO$_{2mean}$/kg (ml·kg-1·min-1)	45.5 ± 5.01	44.8 ± 3.84	.7
VO2mean % of VO2peak	87.4 ± 9.58	85.4 ± 10.37	.6
HRpeak (bpm)	186.3 ± 9.56	183.8 ± 8.54	.5
HRpeak % of HRmax	98.6 ± 5.64	96.6 ± 6.20	.4
HRmean (bpm)	169.2 ± 12.25	171.1 ± 8.20	.6
HRmean % of HRmax	89.5 ± 5.62	89.8 ± 5.40	.9
VO$_{2NANCY}$ % of VO$_{2peak}$	99.4 ± 10.86	96.1 ± 9.75	.4
[LAC]$_{PEAK}$ (mmol·L−1)	9.7 ± 0.96	10.4 ± 0.69	.2
RPE	18.8 ± 0.91	18.7 ± 0.94	.8
	Treadmill VO$_{2peak}$	**Field test VO$_{2peak}$**	
VO$_{2peak}$ (ml·min-1)	3835.2 ± 748.91	3721.7 ± 658.61	.6
VO$_{2peak}$ (ml·kg-1·min-1)	52.7 ± 5.77	51.2 ± 4.80	.3
HRpeak (bpm)	180.4 ± 7.75	185.0 ± 8.91	.08
HRpeak % of HRmax	95.2 ± 4.78	97.6 ± 5.86	.1
RPE	18.1 ± 1.29	18.8 ± 0.91	.07

The Pearson's r analysis showed a significant correlation between the on-field monitored training session finishing times expressed in seconds and the RAST finishing time ($p < .05$), as well as the maximal power output (< .05) in females. In males, the correlation was present only for the maximal power output (< .05).

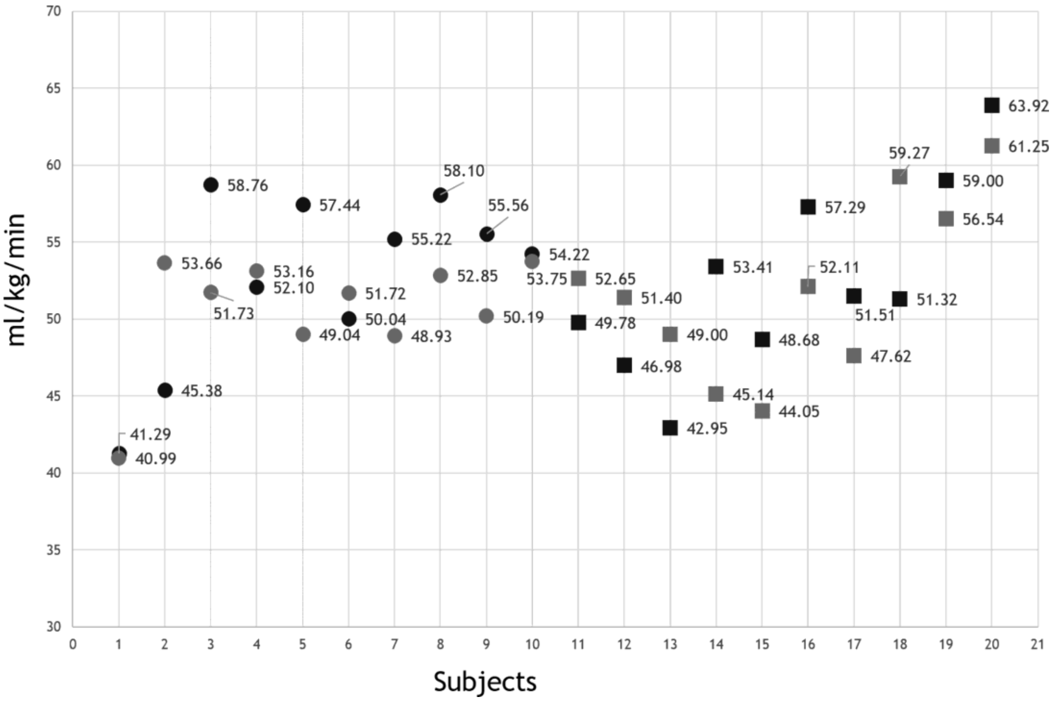

Figure 1. VO_{2peak}/kg values shown for women (squares) and men (dots) for both VO_{2peak} test (shown in black) and On-field test (shown in light grey).

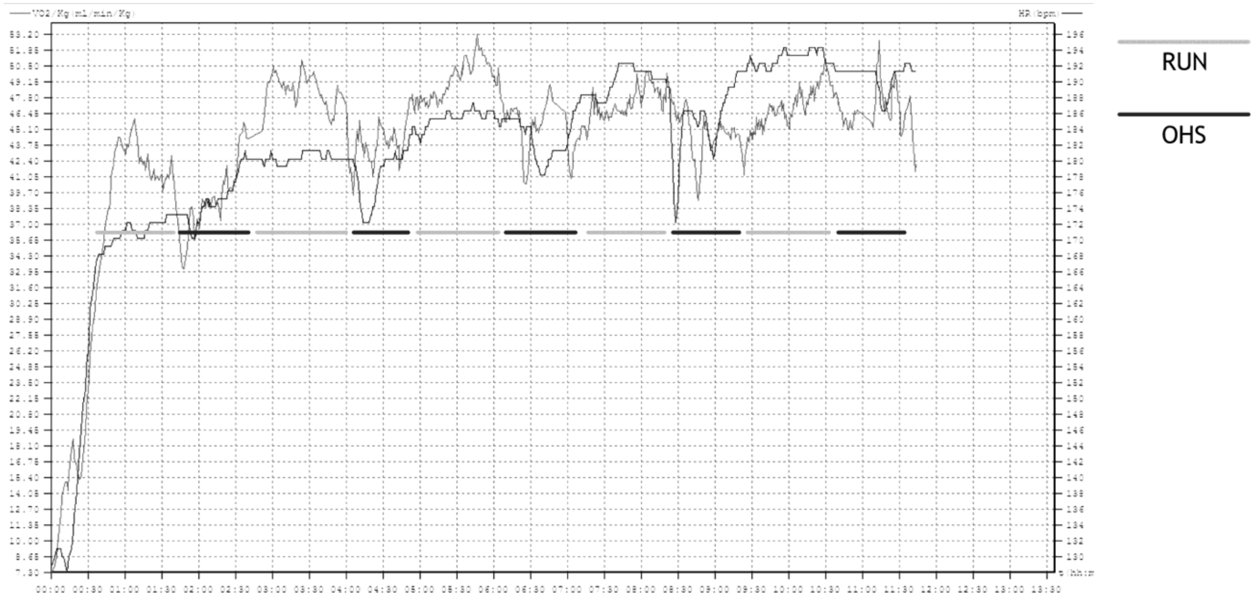

Figure 2 - Typical VO_2 (red line) and HR (blue line) graph recorded during an on-field training session. Underlying bars correspond to run bouts (light green) and over-head squats (OHS) bouts (purple) of the test.

Maximal anaerobic lactic power

The power parameters from RAST are presented in absolute values (W), relative to kg of body mass (W·kg-1) and kg of lean body mass (W·kg LBM-1). PP, MP, top and mean speed values were significantly higher in men compared to women. RAST values are shown in Table 3.

Table 2. Values of variables from RAST expressed in absolute (W) terms, relative to body mass (W·kg-1) and to lean body mass (W·LBM-1).

	Women	Men	p value
Peak Power (W)	311 ± 65.2	639 ± 125.5	< .05
W·kg-1	5.0 ± 1.13	7.6 ± 1.32	< .05
W·LBM-1	6.3 ± 1.29	8.7 ± 1.36	< .05
Mean Power (W)	270.3 ± 63.01	552.6 ± 88.02	< .05
W·kg-1	4.3 ± 1.03	6.6 ± 0.98	< .05
W·LBM-1	5.4 ± 1.1	7.5 ± 0.97	< .05
Top Speed (m·s−1)	5.73	7.0	< .05
Mean Speed (m·s−1)	5.3 ± 0.54	6.1 ± 0.26	< .05
FI (%)	1.9 ± 0.79	4.7 ± 2.64	< .05
Total Time (s)	34.3 ± 1.59	39.8 ± 327	< .05
Minimum Time Per Run (s)	6.1	5.0	< .05
Mean Time Per Run (s)	6.6 ± 0.54	5.7 ± 0.26	< .05
$[LAC]_{PEAK}$ (mmol·L−1)	7.3 ± 1.57	9.8 ± 2.61	< .05

Note: FI, fatigue index.

Lower limb maximal voluntary isometric strength

Results for both dominant and non-dominant legs maximal isometric knee-extension and knee-flexion tests are presented in Table 4. Gender differences were significant for both legs in extension and flexion, with men showing greater strength values than women. FLEX/EXT ratio did not show a significant difference.

Table 4. Maximal isometric knee-extension and knee-flexion for both dominant and non-dominant.

	Women	Men	p value
	Dominant leg	**Dominant leg**	
Extension (N·kg-1)	9.5 ± 2.25	11.7 ± 1.43	< .05
Flexion (N·kg-1)	6.0 ± 1.66	7.1 ± 1.05	< .05
FLEX/EXT (%)	63.4 ± 15.49	63.7 ± 8.11	.9
	Non-Dominant leg	**Non-Dominant leg**	
Extension (N·kg-1)	9.8 ± 1.97	11.7 ± 1.33	< .05
Flexion (N·kg-1)	5.7 ± 1.61	7.4 ± 1.18	< .05
FLEX/EXT (%)	59.4 ± 15.63	61.8 ± 10.92	.6

Note: Flex, flexion; EXT, extension.

Upper limb maximal voluntary isometric strength (handgrip)

Results from the hand grip strength test are presented in Table 5. Gender differences were statistically significant for both dominant and non-dominant arm, with men showing greater strength values than women. Intra-individual strength measures (dominant arm vs. non-dominant arm) were not statistically significant (p = .6 and p = .4 for women and men, respectively).

Table 5. Handgrip strength test values normalized for body mass for both dominant and non-dominant arm.

	Women	Men	p value
Dominant arm (N·kg-1)	0.62 ± 0.110	0.73 ± 0.072	< .05
Non-Dominant arm (N·kg-1)	0.60 ± 0.109	0.71 ± 0.073	< .05

Isokinetic lower limb strength test

Results from the isokinetic lower limb strength test are presented in Table 6. In the 4 repetitions 90°·s-1 test, force normalized per body mass, maximal power and total work were significantly higher in men than women for both legs, in extension and flexion, apart from force normalized per body mass values in flexion. Results from the 20 repetitions 180°·sec-1 test, showed statistically significant differences for maximal power and total work in extension and flexion for both legs, when comparing women to men, with the latter showing higher results. The difference was not statistically significant for force normalized per body mass in extension and flexion.

Table 6. Results from the isokinetic lower limb strength tests. P values are referred to right and left legs comparison between men and women.

	Women		Men		p value	p value
4 reps 90°·s-1	**Right leg**	**Left leg**	**Right Leg**	**Left leg**	**R**	**L**
Force Ext (N·kg-1)	239.9 ± 43.80	243.1 ± 44.13	281.4 ± 28.28	268.9 ± 31.56	< .05	.1
Force Flex (N·kg-1)	161.1 ± 34.95	156.3 ± 35.39	173.2 ± 31.51	162.7 ± 36.66	.4	.6
Power Max Ext (W)	290.7 ± 67.37	301.4 ± 55.98	481.0 ± 73.42	467.1 ± 75.86	< .05	< .05
Power Max Flex (W)	193.5 ± 39.38	198.7 ± 38.59	306.8 ± 68.39	283.4 ± 70.02	< .05	< .05
Total Work Ext (J)	508.9 ± 108.80	484.4 ± 87.57	814.2 ± 136.47	733.0 ± 148.58	< .05	< .05
Total Work Flex (J)	324.4 ± 73.62	308.3 ± 76.70	507.2 ± 149.47	491.8 ± 162.79	< .05	< .05
20 reps 180°·s-1	**Right leg**	**Left leg**	**Right Leg**	**Left leg**	**R**	**L**
Force Ext (N·kg-1)	192.8 ± 30.19	167.7 ± 39.18	203.5 ± 34.30	189.2 ± 29.72	.4	.1
Force Flex (N·kg-1)	141.8 ± 23.04	139.2 ± 28.86	149.3 ± 29.98	133.2 ± 23.49	.5	.6
Power Max Ext (W)	380.1 ± 80.81	398.2 ± 82.55	629.9 ± 111.80	609.3 ± 133.25	< .05	< .05
Power Max Flex (W)	374.0 ± 62.67	451.7 ± 86.74	555.6 ± 173.56	451.7 ± 86.74	< .05	< .05
Total Work Ext (J)	1864.2±346.39	1719.9±353.95	2884.6±637.46	2892.6±635.97	< .05	< .05
Total Work Flex (J)	1408.0±276.25	1256.5±267.48	2101.0±669.48	1893.6±452.02	< .05	< .05

Note: Reps, repetitions; Ext, extension; Flex, flexion.

Maximal anaerobic alactic capacity

Men reached greater values for maximal power output, optimal speed reached, optimal force produced, and jump height compared to women. Since men were heavier, taller and with a larger BSA, force values measured during the jumps are also presented per kg body mass (N·kg-1) and per kg lean body mass (N·kg LBM-1). Values normalized for body mass and lean body mass were significantly greater in men than in women except for optimal force that presented similar values in both groups. Parameters from the countermovement jump are presented in Table 7.

Table 7. Values of variables from countermovement jump test are expressed in absolute terms (W), relative to body mass (W·kg-1) and to lean body mass (W·LBM-1).

	Women	Men	p value
Maximal Power (W)	2700 ± 320	4500 ± 450	< .05
W/kg-1	40 ± 4.8	54 ± 5.9	< .05
W/LBM-1	50 ± 4.7	62 ± 5.7	< .05
Optimal Speed (ms-1)	2.4 ± 0.17	2.8 ± 0.18	< .05
ms-1/kg-1	0.04 ± 0.005	0.03 ± 0.004	< .05
ms-1/LBM-1	0.05 ± 0.004	0.04 ± 0.004	< .05
Optimal Force (N)	1500 ± 220	2100 ± 280	< .05
N/kg-1	20 ± 2.5	25 ± 2.2	.8
N/LBM-1	30 ± 2.7	28 ± 2.6	.1
Jump Height (cm)	31 ± 3.4	39 ± 4.9	< .05

DISCUSSION

The main finding of this study is that HIFT competitive athletes were able to reach high-intensity levels, as revealed by oxygen consumption and lactate production during the on-field monitored training session, which were accompanied by adaptations of multiple physical fitness components, i.e. aerobic fitness, anaerobic power and muscle strength and power, as demonstrated by the laboratory assessment. The lack of specialization in exclusively one domain of physical fitness (e.g. strength, power or aerobic fitness) is the novel finding, which reveals the comprehensive nature of this training methodology. Therefore, HIFT is a modality particularly suitable for general preparedness or multi-sport athletes.

Our anthropometric evaluation has shown the positive effects induced by HIFT, in controlling the amount of subcutaneous fat in both men and women. This is consistent with the results from a recent study, in which researchers showed an overall improvement of body fat percent (-6.5 ± 14.2%fat) and bone mineral content (+0.7 ± 1.9 g/cm2), especially among women, during a 16-weeks HIFT program in a group of apparently healthy adults (Feito, Hoffstetter, Serafini, & Mangine, 2018). Although preliminary, these results are interesting considering the population of women athletes that might be more affected by impaired bone metabolism (e.g. osteoporosis, osteopenia).

From a physical fitness perspective, our results showed the high intensity feature of the on-field monitored training session, compared to the laboratory treadmill test. The high intensity workout achieved near maximal physiological levels (i.e. $HR_{mean} > 89\%$ of HR_{max} and $VO_{2mean} > 85\%$ of VO_{2peak}) and perceived exertion values (RPE values > 18) during the entire workout. Mean HR values recorded during the training session were > 13% and > 15% above the LT, for women and men respectively.

The anaerobic profile and upper range of peak power values, generated by both male and female HIFT athletes in the on-field running based anaerobic test, compared favourably with those produced by athletes in other HIFT studies (Bellar et al., 2015; Butcher, Neyedly, Horvey, & Benko, 2015; Murawska-Cialowicz, Wojna, & Zuwala-Jagiello, 2015) and a range of explosive power-based events (Zupan et al., 2009). These findings confirm the intense anaerobic character of this discipline and suggest that the ability of the whole body to generate high peak power is fundamental during HIFT. Lower limb power also showed a pivotal role in determining the final on-field monitored training session performance, as it was shown by the CMJ tests performed. CMJ muscle power was 54 ± 5.9 W·kg-1 in men and 40 ± 4.8 W·kg-1 in women. To further quantify the two determinants of power production, we measured optimal force and speed. Our results showed that both men and women produce similar levels of optimal force when normalized for body mass and lean body mass, despite a significant difference in optimal speed. Therefore, it can be concluded that women generated less power because they were slower than men. Lower limb strength was further investigated through maximal voluntary leg extension that showed significantly higher values for both dominant and non-dominant limbs in men and women, compared to leg flexion contraction.

Data coming from the isokinetic strength test further demonstrated the difference between leg flexion and extension, with an averaging ratio of 60% in both left and right legs in men and women, for both tests conducted at the two different speed. Force, maximal power and total work values confirmed the considerable strength that extensor muscles have in this group of athletes. Finally, the type of exercise usually performed during HIFT sessions are able to induce significant strength improvements also in upper limbs. This assumption was confirmed by maximal voluntary handgrip values. Our results showed values that were significantly higher for both right and left hand, than what is reported in the literature for age and gender matched individuals (Massy-Westropp, Gill, Taylor, Bohannon, & Hill, 2011).

The test selection process proved to be particularly challenging in this population of athletes. When possible on-field tests and tests adopting exercises that are usually part of the habitual training protocols were preferred. This was the case for the running-based anaerobic sprint test (RAST), which evaluates the anaerobic performance of sports modalities that feature intense and intermittent rhythms, such as team sports and performance on 100m, 200m and 400m sprint in track and field (Zacharogiannis et al., 2004). The RAST has been demonstrated to have the same advantages as the Wingate test albeit without the high cost equipment. It has also been reported that the RAST-obtained anaerobic performance is significantly correlated to the Wingate test (Zacharogiannis et al., 2004; Zagatto, Beck, & Gobatto, 2009). A similar approach was used in the selection of the maximal aerobic fitness test, ensuring that the maximal oxygen consumption was reached before exhausting the athletes with non-specific exercises (Bellar et al., 2015). The population's physical fitness characteristics and type of training are key aspects to be considered when selecting the tests. This applies to elite athletes(Adami et al., 2015; Adami et al., 2019), as well as leisure athletes (Sirico et al., 2019) or patients (Ceccarelli et al., 2019).

The analysis between male and female athletes did not show significant differences when evaluating VO_{2peak}·kg-1 from both the maximal aerobic fitness assessment and on-field monitored training session. Interestingly, statistically significant differences where present for maximal anaerobic power and capacity, maximal voluntary isometric and isokinetic strength, with men having greater values than women. These differences are likely to be attributed to a Testosterone effect on all strength-related parameters, as previously demonstrated (Handelsman, Hirschberg, & Bermon, 2018; Hirschberg et al., 2019).

Thanks to its capacity to promptly stimulating multiple physical fitness improvements, HIFT are often adopted by sedentary individuals. It is strongly recommended that sedentary individuals progressively start increasing their physical activity levels before approaching high intensity and HIFT regimes, to avoid injuries and maladaptive conditions. A "caveat" should also be given to highly trained individuals, who should always allow sufficient resting periods between training sessions, to avoid overtraining consequences.

The results achieved in the present study suggest that further investigations in this field should be considered, particularly with the objective of comparing this population of athletes with athletes from other sports. Furthermore, researchers should consider evaluating a more extensive range of fitness components that are pertinent to the sport. Speed and agility, for instance, are essential for many of the technical and repetitive actions performed in HIFT, but these attributes have received limited research attention. Researchers should also consider addressing the limitations associated with the existing knowledge base, namely the lack of specificity of the testing protocols, standardisation of test procedures and use of equipment.

In conclusion, our research has confirmed the high intensity nature of HIFT and its capacity to determine significant adaptations to multiple physical fitness components. Thanks to the comprehensiveness of HIFT, athletes show exceptional performances in components that are key to many different sports. This suggests that HIFT might be particularly suitable for individuals interested in general preparedness programs or multi-sport athletes. Nevertheless, because of its high intensity a careful and monitored approach is recommended both in beginners as well as in elite athletes.

AUTHOR CONTRIBUTIONS

Authorship: PEA, and AM contributed to the conception or design of the work. PEA, JER, NM and AM contributed to the acquisition, analysis, or interpretation of data for the work. PEA and AM drafted the manuscript. PEA, JER, NM and AM critically revised the manuscript. All gave final approval for publication

on the *Journal of Human Sport and Exercise* and agree to be accountable for all aspects of work ensuring integrity and accuracy.

SUPPORTING AGENCIES

The author(s) received no financial support for the research, authorship, and/or publication of this article.

DISCLOSURE STATEMENT

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Adami, P. E., Delussu, A. S., Rodio, A., Squeo, M. R., Corsi, L., Quattrini, F. M., . . . Bernardi, M. (2015). Upper limb aerobic training improves aerobic fitness and all-out performance of America's Cup grinders. Eur J Sport Sci, 15(3), 235-241. https://doi.org/10.1080/17461391.2014.971878

Adami, P. E., Squeo, M. R., Quattrini, F. M., Di Paolo, F. M., Pisicchio, C., Di Giacinto, B., . . . Pelliccia, A. (2019). Pre-participation health evaluation in adolescent athletes competing at Youth Olympic Games: proposal for a tailored protocol. Br J Sports Med, 53(17), 1111-1116. https://doi.org/10.1136/bjsports-2018-099651

Alcaraz, P. E., Sanchez-Lorente, J., & Blazevich, A. J. (2008). Physical performance and cardiovascular responses to an acute bout of heavy resistance circuit training versus traditional strength training. J Strength Cond Res, 22(3), 667-671. https://doi.org/10.1519/jsc.0b013e31816a588f

Bellar, D., Hatchett, A., Judge, L. W., Breaux, M. E., & Marcus, L. (2015). The relationship of aerobic capacity, anaerobic peak power and experience to performance in CrossFit exercise. Biol Sport, 32(4), 315-320. https://doi.org/10.5604/20831862.1174771

Bemben, M. G., Clasey, J. L., & Massey, B. H. (1990). The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. Res Q Exerc Sport, 61(1), 96-99. https://doi.org/10.1080/02701367.1990.10607484

Borg, G. (1998). Borg's perceived exertion and pain scales: Human kinetics.

Butcher, S. J., Neyedly, T. J., Horvey, K. J., & Benko, C. R. (2015). Do physiological measures predict selected CrossFit((R)) benchmark performance? Open Access J Sports Med, 6, 241-247. https://doi.org/10.2147/oajsm.s88265

Ceccarelli, G., Pinacchio, C., Santinelli, L., Adami, P. E., Borrazzo, C., Cavallari, E. N., . . . d'Ettorre, G. (2019). Physical Activity and HIV: Effects on Fitness Status, Metabolism, Inflammation and Immune-Activation. AIDS Behav. https://doi.org/10.1007/s10461-019-02510-y

Clinical Exercise Testing. (2012). In K. H. J. Wasserman, D. Y. Sue, W. Stringer, K. E. Sietsema, X. G. Sun, & B. J. Whipp (Eds.), Principles of exercise testing and interpretation: Including pathophysiology and clinical applications (5th ed., pp. 129-153). Baltimore: Lippincott Williams & Wilkins.

Feito, Y., Hoffstetter, W., Serafini, P., & Mangine, G. (2018). Changes in body composition, bone metabolism, strength, and skill-specific performance resulting from 16-weeks of HIFT. PLoS One, 13(6), e0198324. https://doi.org/10.1371/journal.pone.0198324

Fernandez-Fernandez, J., Sabido-Solana, R., Moya, D., Sarabia, J. M., & Moya, M. (2015). Acute physiological responses during crossfit® workouts. Eur J Hum Mov, 35, 1-25.

Gallagher, D., Heymsfield, S. B., Heo, M., Jebb, S. A., Murgatroyd, P. R., & Sakamoto, Y. (2000). Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. Am J Clin Nutr., 72(3), 694-701. https://doi.org/10.1093/ajcn/72.3.694

Handelsman, D. J., Hirschberg, A. L., & Bermon, S. (2018). Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. Endocr Rev, 39(5), 803-829. https://doi.org/10.1210/er.2018-00020

Heinrich, K. M., Patel, P. M., O'Neal, J. L., & Heinrich, B. S. (2014). High-intensity compared to moderate-intensity training for exercise initiation, enjoyment, adherence, and intentions: an intervention study. BMC Public Health, 14, 789. https://doi.org/10.1186/1471-2458-14-789

Hirschberg, A. L., Elings Knutsson, J., Helge, T., Godhe, M., Ekblom, M., Bermon, S., & Ekblom, B. (2019). Effects of moderately increased testosterone concentration on physical performance in young women: a double blind, randomised, placebo controlled study. Br J Sports Med. https://doi.org/10.1136/bjsports-2018-100525

Jackson, A. S., & Pollock, M. L. (1978). Generalized equations for predicting body density of men. Br J Nutr, 40(3), 497-504. https://doi.org/10.1079/bjn19780152

Jackson, A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. Med Sci Sports Exerc, 12(3), 175-181. https://doi.org/10.1249/00005768-198023000-00009

Kelly, T. L., Wilson, K. E., & Heymsfield, S. B. (2009). Dual energy X-Ray absorptiometry body composition reference values from NHANES. PLoS One, 4(9), e7038. https://doi.org/10.1371/journal.pone.0007038

Labanca, L., Laudani, L., Menotti, F., Rocchi, J., Mariani, P. P., Giombini, A., . . . Macaluso, A. (2016). Asymmetrical Lower Extremity Loading Early After Anterior Cruciate Ligament Reconstruction Is a Significant Predictor of Asymmetrical Loading at the Time of Return to Sport. Am J Phys Med Rehabil, 95(4), 248-255. https://doi.org/10.1097/phm.0000000000000369

Macaluso, A., & De Vito, G. (2004). Muscle strength, power and adaptations to resistance training in older people. Eur J Appl Physiol, 91(4), 450-472. https://doi.org/10.1007/s00421-003-0991-3

Macaluso, A., Young, A., Gibb, K. S., Rowe, D. A., & De Vito, G. (2003). Cycling as a novel approach to resistance training increases muscle strength, power, and selected functional abilities in healthy older women. J Appl Physiol (1985), 95(6), 2544-2553. https://doi.org/10.1152/japplphysiol.00416.2003

Massy-Westropp, N. M., Gill, T. K., Taylor, A. W., Bohannon, R. W., & Hill, C. L. (2011). Hand Grip Strength: age and gender stratified normative data in a population-based study. BMC Res Notes, 4, 127. https://doi.org/10.1186/1756-0500-4-127

Mathiowetz, V., Kashman, N., Volland, G., Weber, K., Dowe, M., & Rogers, S. (1985). Grip and pinch strength: normative data for adults. Arch Phys Med Rehabil, 66(2), 69-74.

Menotti, F., Bazzucchi, I., Felici, F., Damiani, A., Gori, M. C., & Macaluso, A. (2012). Neuromuscular function after muscle fatigue in Charcot-Marie-Tooth type 1A patients. Muscle Nerve, 46(3), 434-439. https://doi.org/10.1002/mus.23366

Murawska-Cialowicz, E., Wojna, J., & Zuwala-Jagiello, J. (2015). Crossfit training changes brain-derived neurotrophic factor and irisin levels at rest, after wingate and progressive tests, and improves aerobic capacity and body composition of young physically active men and women. J Physiol Pharmacol, 66(6), 811-821.

Queiroga, M. R., Cavazzotto, T. G., Katayama, K. Y., Portela, B. S., Tartaruga, M. P., & Ferreira, S. A. (2013). Validity of the RAST for evaluating anaerobic power performance as compared to Wingate test in cycling athletes. Revista de Educação Física, 19(4), 696-702. https://doi.org/10.1590/s1980-65742013000400005

Rodriguez, N. R., DiMarco, N. M., & Langley, S. (2009). Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J Am Diet Assoc, 109(3), 509-527. https://doi.org/10.1016/j.jada.2009.01.005

Sirico, F., Fernando, F., Di Paolo, F., Adami, P. E., Signorello, M. G., Sannino, G., . . . Biffi, A. (2019). Exercise stress test in apparently healthy individuals - where to place the finish line? The Ferrari corporate wellness programme experience. Eur J Prev Cardiol, 26(7), 731-738. https://doi.org/10.1177/2047487318825174

Stumbo, T. A., Merriam, S., Nies, K., Smith, A., Spurgeon, D., & Weir, J. P. (2001). The effect of hand-grip stabilization on isokinetic torque at the knee. J Strength Cond Res, 15(3), 372-377.

Thompson, W. R. (2013). Now trending: worldwide survey of fitness trends for 2014. ACSM's Health & Fitness Journal, 17(6), 10-20. https://doi.org/10.1249/fit.0000000000000252

Thompson, W. R. (2018). Worldwide Survey of Fitness Trends for 2019. ACSM's Health & Fitness Journal, 22(6), 10-17. https://doi.org/10.1249/fit.0000000000000438

Tibana, R., de Sousa, N., Prestes, J., & Voltarelli, F. (2018). Lactate, Heart Rate and Rating of Perceived Exertion Responses to Shorter and Longer Duration CrossFit® Training Sessions. J Funct Morphol Kinesiol, 3(4), 60. https://doi.org/10.3390/jfmk3040060

Wasserman, K., Beaver, W. L., & Whipp, B. J. (1986). Mechanisms and patterns of blood lactate increase during exercise in man. Med Sci Sports Exerc, 18(3), 344-352. https://doi.org/10.1249/00005768-198606000-00017

Zacharogiannis, E., Paradisis, G., & Tziortzis, S. (2004). An evaluation of tests of anaerobic power and capacity. Med Sci Sports Exerc, 36(5), S116. https://doi.org/10.1249/00005768-200405001-00549

Zagatto, A. M., Beck, W. R., & Gobatto, C. A. (2009). Validity of the running anaerobic sprint test for assessing anaerobic power and predicting short-distance performances. J Strength Cond Res, 23(6), 1820-1827. https://doi.org/10.1519/jsc.0b013e3181b3df32

Zupan, M. F., Arata, A. W., Dawson, L. H., Wile, A. L., Payn, T. L., & Hannon, M. E. (2009). Wingate Anaerobic Test peak power and anaerobic capacity classifications for men and women intercollegiate athletes. J Strength Cond Res, 23(9), 2598-2604. https://doi.org/10.1519/jsc.0b013e3181b1b21b