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Original

The effects of high-intensity functional training on muscle damage and recovery capacity in trained individuals

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ABSTRACT

Objective: High-Intensity Functional Training (HIFT) is nowadays widely used due to low time demand and efficiency to improve performance and health. The dynamics of recovery of muscle damage and physical fitness after a HIFT in individuals with different fitness status provide a practical information for coaches and practitioners. Therefore, the aim of this study was to verify the muscle damage and performance recovery responses after an acute HIFT session in healthy young men with different fitness status.
Method: Sixteen recreationally trained participants (age: 23.4 ± 2.4 y; body mass index: 24.6 ± 2.4 kg·m-2; 1RM back squat: 120.1 ± 19.9 kg) were divided into two groups according to their maximum strength (higher-trained [HT] and lower-trained group [LT]), and performed a single HIFT session. Muscle damage (creatine kinase [CK] and lactate dehydrogenase [LDH]) and physical fitness tests (strength, power, and oxygen consumption) were analyzed before, immediately after, 24h and 48h after the HIFT session. The internal training load for both groups was equalized using the Rating of Perceived Exertion method (RPE) and the percentage 1 repetition maximum (1RM).
Results: Biochemical markers and performance indicators showed that both groups suffered exercise-induced muscle damage. There was a trend towards faster muscle damage recovery in HT group.
Conclusions: HT group showed higher muscle damage recovery compared to the LT group. A longer recovery time to complete muscle recovery might be expected in the LT group.
Keywords: Fatigue; Physical fitness; Recovery; Intermittent training.

Los efectos del entrenamiento funcional de alta intensidad sobre el daño muscular y la capacidad de recuperación en individuos entrenados

RESUMEN

Objetivo: El Entrenamiento Funcional de Alta Intensidad (HIFT) se utiliza hoy en día ampliamente debido a la baja demanda de tiempo y la eficiencia para mejorar el rendimiento y la salud. La dinámica de recuperación del daño muscular y la forma física después de un HIFT en individuos con diferentes estados de forma proporcionan una información práctica para entrenadores y profesionales. Por lo tanto, el objetivo de este estudio fue verificar el daño muscular y las respuestas de recuperación del rendimiento después de una sesión aguda de HIFT en hombres jóvenes sanos con diferentes estados de forma física.
Método: Dieciséis participantes entrenados de forma recreativa (edad: 23,4 ± 2,4 y; índice de masa corporal: 24,6 ± 2,4 kg-m-2; 1RM back squat: 120,1 ± 19,9 kg) se dividieron en dos grupos en función de su fuerza máxima (grupo de mayor entrenamiento [HT] y grupo de menor entrenamiento [LT]), y realizaron una única sesión de HIFT. Se analizaron el daño muscular (creatina quinasa [CK] y lactato deshidrogenasa [LDH]) y las pruebas de aptitud física (fuerza, potencia y consumo de oxígeno) antes, inmediatamente después, 24h y 48h después de la sesión de HIFT. La carga de entrenamiento interna para ambos grupos se igualó utilizando el método de Valoración del Esfuerzo Percibido (RPE) y el porcentaje de 1 repetición máxima (1RM).
Resultados: Los marcadores bioquímicos y los indicadores de rendimiento mostraron que ambos grupos sufrieron daños musculares inducidos por el ejercicio. Hubo una tendencia a una recuperación más rápida del daño muscular en el grupo HT.
Conclusiones: El grupo HT mostró una mayor recuperación del daño muscular en comparación con el grupo LT. Podría esperarse un mayor tiempo de recuperación hasta la recuperación muscular completa en el grupo LT.

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Palabras clave: Fatiga; Condición física; Recuperación; Entrenamiento intermitente.

Os efeitos do treinamento funcional de alta intensidade sobre dano muscular e capacidade de recuperação em participantes treinados

RESUMO

Objetivo: Treinamento Funcional de Alta Intensidade (HIFT) é hoje amplamente utilizado devido à baixa demanda de tempo e eficiência para melhorar o desempenho e a saúde. A dinâmica de recuperação dos danos musculares e da aptidão física após um HIFT em indivíduos com diferentes estados de aptidão física fornece uma informação prática para treinadores e praticantes. Portanto, o objetivo deste estudo foi verificar as respostas dos danos musculares e da recuperação do desempenho após uma sessão HIFT aguda em homens jovens saudáveis com diferentes estados de condicionamento físico.

Método: Dezesseis participantes treinados recreacionalmente (idade: 23,4 ± 2,4 anos; índice de massa corporal: 24,6 ± 2,4 kg-m-2; 1RM de cócoras: 120,1 ± 19,9 kg) foram divididos em dois grupos de acordo com sua força máxima (grupo mais bem treinado [HT] e grupo menos treinado [LT]), e realizaram uma única sessão HIFT. Os danos musculares (creatina cinase [CK] e lactato desidrogenase [LDH]) e testes de aptidão física (força, potência e consumo de oxigênio) foram analisados antes, imediatamente depois, 24h e 48h após a sessão HIFT. A carga de treinamento interno para ambos os grupos foi equalizada usando o método RPE (Rating of Perceived Exertion) e o percentual 1 máximo de repetição (1RM).

Resultados: Os marcadores bioquímicos e os indicadores de desempenho mostraram que ambos os grupos sofreram danos musculares induzidos por exercícios. Havia uma tendência para uma recuperação mais rápida dos danos musculares no grupo HT.

Conclusões: O grupo HT mostrou maior recuperação do dano muscular em comparação com o grupo LT. Um tempo de recuperação mais longo pode ser esperado para a recuperação muscular completa no grupo LT.

Palavras-chave: Fadiga; Aptidão física; Recuperação; Treinamento intermitente.

Introduction

High-Intensity Functional Training (HIFT) is a time-efficient training mode widely used in recreational participants.[1] This training program involves repeated short (less than 45 seconds) to long (two or more minutes) bouts of high intensity efforts such as endurance and resistance exercises interspersed with incomplete recovery periods.[1] Recent research on HIFT has reported high energy expenditure, improvements in body composition and absolute strength.[2, 3]

HIFT results in exercise-induced muscle damage (MD) and post-exercise fatigue.[4,5] The MD consists of structural muscle disruption as a result of mechanical stress and accumulation of metabolites, culminating in the release of muscle enzymes such as creatine kinase (CK) and lactate dehydrogenase (LDH), resulting in a decline in performance (loss of strength and power).[6] Recently, many studies have shown a strong relationship between HIFT and MD.[5, 7] Gomes et al.[8] investigated MD following a single 'Cindy' workout session (classified as HIFT) in adult practitioners. The workout elicited significant acute perturbations in the analyzed muscle cells by increased CK activity after the exercise bout (174.9 to 226.7 I.L-1), which remained elevated 24h after the end of the training session. Ertel et al.[9] described the intensity of the training session as the main cause to the MD. Also, it was irrespective to the participants' training level. Recently, Tibana et al.[10] showed that eight recreational male participants increased their CK levels one hour after a HIFT workout compared to those who performed all-out intensity, while those who performed moderate-intensity HIFT workout (rating perceived exertion 6 [RPE]) did not increase their CK levels as much as the all-out intensity group.

Training intensity and short rest intervals are the key factors in muscle damage.[5, 11] Tibana et al.[11] reported that nine HIFT athletes tended to increase their CK levels after three days of HIFT with the CK values decreasing only 72h after HIFT workout. According to the authors, this phenomenon may have affected the performance of the study participants. Although the HIFT compromises metabolic, gymnastic and weightlifting exercises, the weightlifting exercises performed at high intensity (multiple repetitions and sets) has been shown to impair performance more than the other variables (i.e., metabolic and gymnastic exercises).[12] The power clean and the snatch movements are common in HIFT-workouts. They are usually performed at submaximal intensities and, as a result, movement velocities and repetitions are higher. Mate-Munoz et al.[4] described that maximum repetitions of the power clean at 40%1RM increased the lactate levels more than 10 fold. Thus, it is expected that HIFT-workouts involving weightlifting exercises lead to higher training loads than metabolic movements, also resulting in longer recovery periods to restore performance.[4]

Recovery after the HIFT workout is necessary to reverse the negative effects of the fatigue process and allow performance improvement.[13] Previous studies on MD time recovery have reported that 24 h after HIFT workout is not sufficient to reestore the muscle structure and function.[5, 6, 10] Interestingly, none of these studies investigated the MD time recovery between individuals of different training levels aiming to understand the dynamics of performance and MD recovery.

In addition to the fact that HIFT is able of increase lactate more than 10-fold and increase CK levels, the literature also describe several key points related to the physiological efficacy of training, such as the improvement of physical capacity, including aerobic and anaerobic capacity, anaerobic power, cardiovascular fitness, body fat reduction, and the ability to maintain high lactate levels during high-volume training.[14] Recently, Meier et al.[15] reported that participants of different training levels who trained with HIFT achieved similar HR behaviour, which is possible due to the HIFT design that combines aerobic and anaerobic exercises intensities. Despite this fact, the more experienced HIFT participants are able to withstand higher loads (i.e., heavier loads [kg]). In this sense, studies investigating the effects of HIFT on MD and performance in subjects with different levels of training are scarce. Therefore, we aimed to investigate exercise-induced MD and recovery utilizing biochemical markers and performance indicators according to fitness status to gain a better understanding of the time-course of recovery in higher and lower trained subjects. Based on previous literature,[7, 16, 17] we hypothesized that higher trained participants should experience less MD and recover quickly when compared with lower trained participants exposed to the same training protocol.

Material and methods

Participants

The sample size was obtained by calculating sample power through the number of observations, using the article by Johnston et al.,[18] taking into account variables common to this study, such as CK and lower-limb power measured by the Counter Movement Jump (CMJ), guaranteeing a statistical power of 0.95 and alpha of 5% (software G*Power – Dusseldorf, Germany). Sixteen trained male participants were divided into 2 equal groups (8 each): higher-trained (HT, Age: 24.6 ± 4 years; BMI: 21.6 ± 2.8 kg·m-2;

training experience: 3 ± 1.3 years) and lower-trained (LT, Age: 22.3 ± 2.9 years; BMI: 20.5 ± 1.6 kg·m-2; training experience: 2.7 ± 1.5 years) according to lower-limb relative strength (for the back squat exercise) and training history (physical activity practice for at least for 1 year for the first group, with training frequency maintained, and training time not determined for the second group, with non-systematic physical training). The participants were included if they met the following criteria: training experience of at least one year; at least one national/international competition before 2022, and free of medication or performance enhancing drugs based on a questionnaire. The recommendation was to avoid changes in dietary parameters and no additional exercise during the trials. Individuals with pre-existing diseases or injuries were excluded from the protocol. They signed the free and informed consent approved by the local research ethics committee (Nº: 73304717.0.0000.5659). All the experiments complied with current legislation (Declaration of Helsinki).

Experimental Design

Participants visited the pre-established local 5 times. At the first contact - day 0 (D0), anthropometric measurements were taken and they performed partial HIFT workout to familiarize themselves with the training session (one set of HIFT session; suggested RPE = 5). Forty-eight hours after de D0, the participants were engaged to perform four different procedures: 1. Blood sampling; 2. Vertical jumps - Squat Jump (SJ), Counter Movement Jump (CMJ) and Drop Jump (DJ); 3. 1RM test; 4. Incremental treadmill test. Forty-eight hours after D1, on day 3 (D3), they performed the proposed HIFT workout and immediately afterwards all the above-mentioned tests were performed in the same order ("post-test"). All the procedures were repeated after 24 and on 48 h after the HIFT session (**Figure 1**).

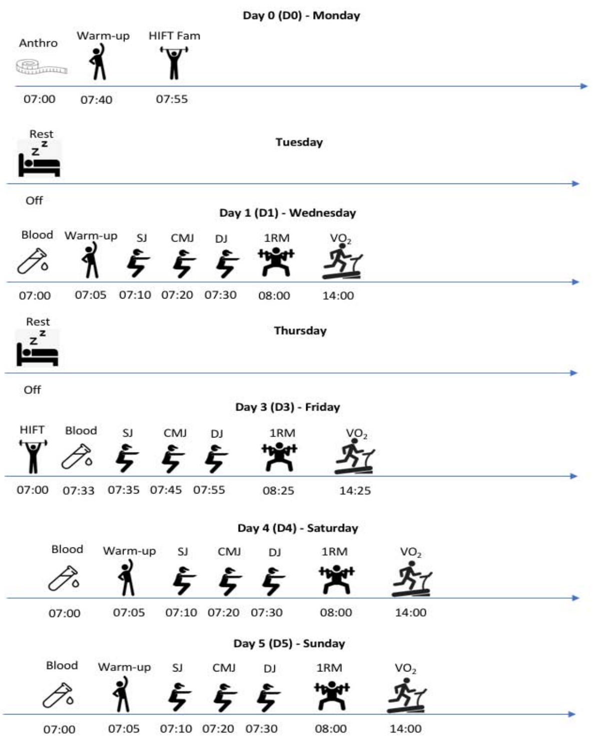

Figure 1. Experimental design. Note: Anthro, Anthropometry; HIFT, high-intensity functional training; HIFT Fam, high-intensity functional training familiarization; Blood, blood sample; SJ, squat jump; CMJ, Counter Movement Jump; DJ, Drop Jump; 1 RM, 1 repetition maximum.

Procedures

The analyzed variables to determine muscle damage (MD) and recovery behaviour were 1. Enzymatic activity of CK and LDH and 2. Physical performance (strength, power and estimation of maximal oxygen consumption).

Strength test

To measure maximum strength, the 1RM test which is a valid and reliable method to determine maximal strength was performed for the back-squat exercise.[19, 20] The back-squat started with the barbell on the rack. The subjects positioned the barbell on the shoulder with extended wrists and flexed elbows. The Subjects' feet were shoulder-width apart, with the toes pointing forward and slightly outwards. Subjects squatted at a knee angle of approximately 120º and then fully extended their hips and knees. The exercise was examined through visual inspection by an experienced instructor who had 10 years of coaching experience with weightlifters. [21]

All the participants had experience with the protocol. Initially, to perform a warm-up, the participants do a stimulus of 5 to 10 repetitions at 40-60% of the predicted maximum load; 1 minute of passive interval; the second stimulus of 3 to 5 repetitions at 60-80% of the predicted maximum load; passive 2 minutes rest; the third stimulus of 2 to 3 repetitions with 90% of the predicted maximum load. Finally, after a passive rest (3 to 5 minutes), the participants had their first attempt to perform the 1RM. If the practitioner performed more than one complete repetition (eccentric and concentric phase) in the final test phase, the attempt was repeated after a 3 to 5 minutes interval. If the 1RM was not obtained in 3 attempts the participant repeated the protocol after an interval of 48 hours. [22]

Power test

To verify lower limb power the groups performed three types of vertical jumps which proved to be valid and provide high reliability – Squat Jump (SJ), Countermovement Jump (CMJ) and Drop Jump (DJ) at a sectorized mat Ergo Jump Platform (Cefise®, Nova Odessa – Brazil).[23] SJ: standing on the mat, with feet parallel right under the shoulders and hands resting on waist the participant performed a vertical jump starting in the 90º flexion position of the knee. CMJ: following the same position before the participant started from the upright position to perform the simultaneous knee and hip flexion and extension, for the subsequent performance of vertical jump. DJ: falling from the top of a 40 cm box to the mat, trying to get out of the mat as soon as the feet touched it and avoiding hip or knee flexion. There were 3 attempts for each jumping technique (SJ, CMJ and DJ), with intervals of 1 minute between attempts of the same technique and 5 minutes between different techniques. For statistical analysis, it was considered the best jump between the three attempts of each jumping technique.

Estimative of maximal oxygen consumption (VO2max)

Both groups performed the incremental test on a treadmill using the Ellestad protocol which is a well-stabilized protocol to assess the VO2max (24, 25). The test started with 3 minutes of walking at 2.7 km/h at a 10% grade, followed by three stages 2 minutes each at 4.8; 6.4 and 8km/h; 3 minutes of running at 8 km/h at 15% grade, followed by 2 minutes at 9.7; 11.3; 12.9; 14,5; 16.1; 17.7; 19.3; 20.9; 22.5 km/h or until fatigue. Thus, from time (t) in minutes obtained, the estimative of VO2max was establish by equation:

VO2max (ml·kg-1·min-^{1}) = 4,46 + (3,933 * t).[24]

HIFT workout

The training load for both groups was equalized by RPE-8 on a scale from 0 to 10 (CR-10), and through 1RM for squat exercise (70%1RM). Participants performed a standardized warm up protocol walking on a treadmill at 6km/h for 5 minutes followed by 3 sets of 2 mobility exercises lasting 6 minutes (1. adduction and abduction; 2. flexion and extension of hips and shoulders simultaneously) during 40 seconds with 20 seconds of passive recovery between exercises and series. After three minutes of rest, the HIFT session composed by 3 sets of Back Squats (70% 1RM); Shoulder presses (self-determined load following RPE-8); Burpees; Abdominal Sit-Ups for 40 seconds (at self-selected close to maximal intensity considering RPE 8) with a passive recovery of 60 seconds between each exercise and series was performed. **Table 1** summarizes such information of the HIFT protocol.

Table 1. Warm up, mobility and HIFT workout structure.

	EXERCISES	DURATION (t)	INTENSITY	REST (t)	TOTAL (t)
WARM UP	Treadmill walk	5'	6km/h	-	5'
MOBILITY (3 sets)	Adduction and abduction[1]	40''	RPE - 4	20''	-
	Flexion and extension[1]	40''	RPE - 4	20''	-
	TOTAL	9'	-	2'	11'
PASSIVE REST					3'
HIFT SESSION (3 sets)	Squat	40''	70% 1RM	60''	-
	Shoulder press	40''	Self-selected load (RPE - 8)	60''	-
	Burpee	40''	RPE - 8	60''	-
	Sit Up	40''	RPE - 8	60''	-
	TOTAL	8'	-	11'	19'
WARM UP + MOBILITY + HIFT SESSION					33'

[1]hips and shoulders simultaneously. Note: RPE, Rating perceived exertion; t, time. ('), minute/s; (''), seconds; RM, repetition maximum.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics software, version 22.0 for Windows. The normality of the data (Shapiro-Wilk) and the Mauchly's sphericity test were verified, and violation was detected for sphericity test. The repeated measures of ANOVA (group x time) were used after the univariate analysis for correction. Repeated measures of ANOVA were computed to determine possible differences between and within the values of CK and LDH activities, jump performance, maximum strength, and aerobic power as a function of the groups analyzed and evaluation of the times pre- and post- HIFT workout. Bonferroni post-hoc test was used. To characterize the size of the effects, the Partial eta-squared ($\eta p2$) was also computed (26). The significance level was pre-fixed at 5% ($p < 0.05$).

Results

Participants

The characteristics of the participants and groups are shown in **Table 2**.

Table 2. Characteristics of participants.

Variables	*HT (n = 8)* Mean ± SD (95% CI)	*LT (n = 8)* Mean ± SD (95% CI)	*p* (η_p^2) Between group differences (95% CI)
Age (years)	24,6 ± 4 (21.5-29.9)	22,2 ± 2,9 (19.7-24.7)	0.201 (0.62)
Height (cm)	173.1 ± 4.6 (1.69-1.76)	177.5 ± 4.6 (1.73-1.81)	0.080 (0.94)
Body mass (kg)	74.8 ± 10.8 (65.7-83.9)	76.43 ± 6.1 (81.2-81.5)	0.733 (0.17)
Load on 1RM (kg)	137.2 ± 29.4 (112.6-161.8)	103.00 ± 10.4 (94.2-111.7)*	0.008 (1.55)
Relative Strength[1] (a.u.)	1.8 ± 0.2 (1.6-2)	1.34 ± 0.7 (1.2-1.8)*	0.001 (2.82)

Note: HT, higher trained; LT, low trained; cm, centimeters; kg, kilogram; RM, maximum repetition; a.u., arbitrary units; *: significant differences from HT group [1]squat exercise.

CK activity was only significantly increased between groups comparing pre-HIFT workout (eta=0.10; p=0.043). Despite this result, CK increased 52% comparing pre-HIFT workout for HT group vs. post-HIFT workout LT group (eta=0.98; p=0.347); 65% comparing 24h post-HIFT workout LT group vs. pre-HIFT workout HT group (eta=0.75; p=0.589); 86% comparing 48h post-HIFT workout LT group vs. pre-HIFT workout HT group (eta=0.89; p=0.769); 62% comparing post-HIFT workout HT group vs. post-HIFT workout LT group (eta=0.37; p=0.328); 32% comparing 24h post-HIFT workout LT group vs. post-HIFT workout HT group (eta=0.44; p=0.795): 48% comparing 48h post-HIFT workout LT group vs. post-HIFT workout HT group (eta=0.98; p=0.396); 62% comparing 24h post-HIFT workout HT group vs. 24h post-HIFT workout LT group (eta=0.72; p=0.961); 35% comparing 24h post-HIFT workout HT group vs. 48h post-HIFT workout LT group (eta=0.42; p=0.948); and finally, 30% comparing 48h post-HIFT workout HT group vs. 48h post-HIFT workout LT group (eta=0.66; p=0.991). **Figure 2a** shows the time course of CK activity between and within groups.

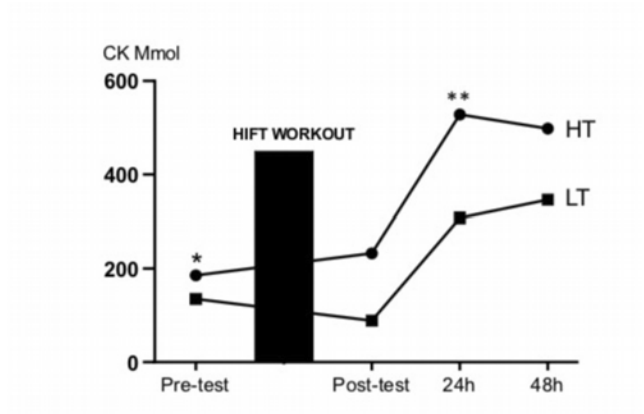

Figure 2a. Time course of CK concentration pre- and post- HIFT workout. Note: Main values (standard error). CK, creatine kinase; HIFT: high-intensity fitness training; HT, higher trained group; LT, lower trained group. *, difference between groups (pre-test); **, difference within groups to post-test.

LDH did not change between or within groups pre-, post-, 24h post- or 48h post-HIFT workout (n.s.). Despite these results, LDH increased 5.5% comparing pre-HIFT workout HT group vs. pre-HIFT workout LT group (eta=0.23; p=0.847); 11% comparing pre-HIFT workout HT group vs. post-HIFT workout LT group (eta=0.43; p=0.792); 7% comparing 24h post-HIFT workout LT group vs. pre-HIFT workout HT group (eta=0.23; p=0.922); 41%

comparing 48h post-HIFT workout LT group vs. pre-HIFT workout HT group (eta=1.35; p=0.526); 7% comparing post-HIFT workout HT group vs. post-HIFT workout LT group (eta=0.30; p=0.648); 11% comparing 24h post-HIFT workout LT group vs. post-HIFT workout HT group (eta=0.37; p=0.692): 47% comparing 48h post-HIFT workout LT group vs. post-HIFT workout HT group (eta=1.53; p=0.484); 8% comparing 24h post-HIFT workout HT group vs. 24h post-HIFT workout LT group (eta=0.37; p=0.376); 21% comparing 48h post-HIFT workout LT group vs. 24h post-HIFT workout HT (eta=0.78; p=0.921); and finally, 6.5% comparing 48h post-HIFT workout LT group vs. 48h post-HIFT workout HT group (eta=0.22; p=0.638). **Figure 2b** shows the time course of LDH activity between and within groups.

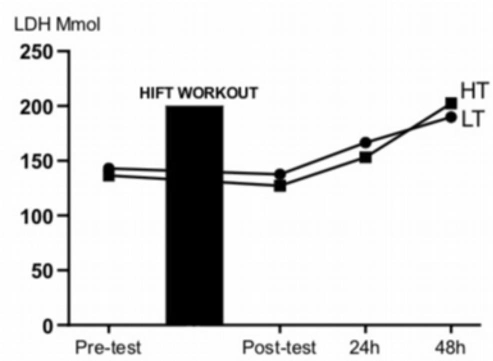

Figure 2b. Time course of LDH concentration pre- and post- HIFT workout. Note: Main values (standard errors). CK, creatine kinase; HIFT: high-intensity fitness training; HT, higher trained group; LT, lower trained group. *, difference between groups (pre-test); **, difference within groups to post-test.

Our results showed significant differences between groups for 1RM at all time points comparing HT vs. LT at pre-test (eta=0.40; p=0.008); post-test (eta=0.37; p=0.012); 24h (eta=0.42; p=0.006) and 48h (eta=0.46; p=0.013) and also for relative strength comparing HT vs. LT in pre-test (eta= 0.65; p<0.001); post-test (eta=0.60; p<0.001); 24h (eta= 0.66; p<0.001) and 48h (eta=0.58; p=0.001). There were no differences between the two groups for moments of the vertical jump and the relative power in "W·kg-1" measured at the SJ, CMJ and DJ for estimation of oxygen consumption (n.s.). However, significant differences were observed for the vertical jump in "cm" from CMJ reduced post-HIFT workout for both groups, demonstrating lower limb fatigue, pre-HIFT workout vs. post-HIFT workout for HT group (eta=1.11; p=0.024) and LT group (eta=0.80; p=0.017) and from relative CMJ values comparing pre-HIFT workout vs. post-HIFT workout for HT group (eta=1.11; p=0.035) and LT group (eta=0.76; p=0.019). The LT group reduced the VO2max right post-HIFT workout, pre-HIFT workout vs. post-HIFT workout for LT group (eta=1.21; p=0.001). Data pertaining the performance variables are exposed in **table 3**.

Discussion

The aim of this study was to verify the acute MD and the time course of recovery after a HIFT workout in two different groups. A novel finding is that CK or LDH did not change over time between LT and HT groups. Also, the HT group had higher CK activity pre-HIFT when compared to the LT group, and CK activity was significantly increased after 24 h compared to the HT group post-HIFT. Our hypothesis was not confirmed since the HT group had higher MD values after HIFT workout.

This it is not the first study to observe physiological impairments prior to HIFT workout in higher trained participants. Perciavalle et al.[27] investigated the lactate responses in professional female CrossFit athletes performing a HIFT workout. Pre-HIFT lactate levels were found to be higher than those normally found at rest (4.5mmol).

Timón et al.[28] found that two days of HIFT workout in trained male participants increased the CK levels, which returned to basal levels after 48h of HIFT workouts. CK, which represents muscle damage and metabolism may provide information about training intensity. Therefore, the results of the present study suggest that muscle damage occurs after a single HIFT-workout in trained participants, probably due to their previously demonstrated ability to perform exercises at higher intensities.[15]

Although the CK levels were higher in the HT group, this did not affect the participants' ability to recover the lower limbs power. The HT and LT groups showed a decrease in lower limb power post-HIFT workout, but this was restored after 24 h after the training workout.

Tibana et al.[6] reported that two days of HIFT workout impaired pro- and anti-inflammatory cytokines and osteoprotegerin without impairing lower limbs muscle strength in experienced HIFT workout male participants. These results corroborate previous studies by our research group, which recently showed that two days of simulated competition did not impair anaerobic power or fatigue in HIFT athletes.[29] Timón et al.[28] investigated two days of HIFT workouts (two training workouts including weightlifting, metabolic and gymnastic exercises) on biochemical parameters and physical performance (plank test) in trained HIFT participants (VO2max: 47.8 ± 3.6 ml.kg.min-1, 1RM power clean: 93.2 ± 7.6kg). Both, physical performance and biochemical parameters such as blood glucose, hepatic transaminases, and CK were impaired for 24h after the training workouts completed and returned to basal levels after 48 h of training workouts.

Regarding the VO2max, only the LT group decreased the VO2max post-HIFT workout, reestablishing its values after 24h HIFT workout. Interestingly, there were no differences in pre-VO2max test between groups, however, the LT group decreased their VO2max post-HIFT workout. Here, the HT group did not decrease their VO2max post-HIFT workout. Studies evaluating participants at different levels of training have shown that, in part, the movement economy (ME) plays an important role in training and race performance.[30] In brief, factors such as metabolic efficiency, cardiorespiratory efficiency, training experience, biomechanical efficiency, and neuromuscular efficiency are able to determine the most ME athletes. Although we did not evaluate the ME, it is expected that the HT group would have better ME than the LT group.

This manuscript is not free of imitations, among them we can mention: i) many aspects influencing recovery were not investigated, ii) the absence of a control group, iii), the dietary and resting control of the participants was not performed in the periods before the collections. Our finds reveal the acute effects of HIFT-workout on MD and recovery regarding training status, additional research should be conducted aiming to understand the chronic effects of HIFT-workout on these variables. Besides that, this study strengthens the evidence that trained subjects are able to exercise more for the same relative intensity than less trained subjects. Additionally, the time required to recover their biological functions appears to be shorter.

Conclusion

In conclusion, a single HIFT session utilizing squat, shoulder press, burpee and sit-up movements elicited a significant level of CK in the HT group 24 h after the training session. More importantly, the results showed a higher basal CK activity in the HT group compared to the LT group, indicating a poor recovery from the last training/exercise programme. Coaches and practitioners should be advised of the potential MD caused by a single HIFT session in trained participants. Further research is needed to better clarify the similarities or differences between the physiological markers of MD, neuromuscular performance and a single HIFT session.

Practical Applications

Practitioners may use neuromuscular and physiological assessments to determine the potential effects of a HIFT session on trained participants. Analysis of CK activity is important to prevent loss of performance and reduce the risks of injury. This study supports previous studies that have shown CMJ to be a predictor of fatigue and stress.[31, 32] Training intensity and volume management should be considered following neuromuscular and physiological assessments to improve training performance. Finally, this information may be useful for coaches to optimize the training prescription and minimize the potential negative effects associated with the performance of the HIFT session.

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Table 3. Values of performance parameters at pre-, post-, 24h-post, and 48-post high intensity functional training workout on lower trained and higher trained groups.

	Pre-test		Post-test		24h after		48h after	
	HT	**LT**	**HT**	**LT**	**HT**	**LT**	**HT**	**LT**
Height SJ (cm)	36.4 ± 3.86 (34.2-40.6)	34.65 ± 4.15 (32.2-39.1)	33.5 ± 7.00 (27.4-39.2)	32.1 ± 4.42 (29.7-37.1)	34.35 ± 4.93 (32-40.3)	34.6 ± 4.2 (32-39)	33.45 ± 6.6 (30.2-41.3)	32.9 ± 5.4 (29-38.1)
Height CMJ (cm)	39.5 ± 5.8 (36.4-46.1)	37.4 ± 3.6 (35.7-41.8)	36.5 ± 3.1 (33.4-38.7)*	34.1 ± 4 (32.3-39.1)*	38.1 ± 6 (35-45)	37.6 ± 5.1 (34.9-43.4)	39 ± 6.6 (33.6-44.7)	35.1 ± 6.6 (30.8-41.8)
Height DJ (cm)	29.6 ± 6.4 (23.3-34.1)	34.15 ± 7.1 (27-38.9)	30.05 ± 6.4 (24.5-35.2)	27.4 ± 6.4 (22.6-33.5)	29.75 ± 8.1 (24.4-38.1)	30.3 ± 5.5 (24.1-33.3)	26 ± 10.4 (20.1-37.6)	27.7 ± 4.7 (24.2-32.1)
Relative Power SJ (W·kg-1)	47.7 ± 5.3 (42.6-51.5)	45.9 ± 3.7 (43.8-50)	45 ± 5.6 (40.1-49.5)	43.9 ± 3.6 (41.9-48)	45.7 ± 3.7 (44-50.2)	45.9 ± 3.5 (43.7-49.6)	44.9 ± 6.3 (40.6-51.2)	44.4 ± 4.5 (41.2-48.8)
Relative Power CMJ (W·kg-1)	49.9 ± 4.8 (47.6-55.4)	48.2 ± 3.3 (46.5-52.2)	47.7 ± 2.5 (45.1-49.3)*	45.4 ± 3.3 (44-49.5)*	48.7 ± 4.9 (46.2-54.5)	48.5 ± 4.3 (46-53.2)	49.7 ± 6 (43.3-53.4)	46.2 ± 5.5 (42.7-51.9)
Relative Power DJ (W·kg-1)	42.1 ± 5.9 (35.7-45.7)	45.5 ± 5.4 (40.1-49.2)	41.7 ± 4.8 (36-44.1)	40.2 ± 4.9 (46.4-44.7)	41.8 ± 6.8 (37.1-48.5)	42.2 ± 4.5 (37.1-44.8)	38.5 ± 9.6 (31.4-47.6)	40.1 ± 3.7 (37.5-43.8)
1RM (kg)	143 ± 29.4 (112.6-161.8)	103 ± 10.4 (94.2-111.1)	128 ± 26.8 (107.8-152.6)	102 ± 10.9 (91.3-109.6)	140 ± 29.3 (111.4-160.5)	100 ± 10.7 (91.5-109.4)	142 ± 32.1 (108.9-162.5)	99 ± 11.4 (91.9-111)
Relative Strength (u.a.)	1.7 ± 0.2 (1.6-2)	1.3 ± 0 (1.2-1.4)	1.6 ± 0.2 (1.5-1.9)	1.3 ± 0.0 (1.2-1.3)	1.7 ± 0.2 (1.5-2)	1.3 ± 0.0 (1.2-1.3)	1.7 ± 0.2 (1.5-2)	1.3 ± 0.1 (1.2-1.4)
VO_2máx (ml·kg-1·min-[1])	44.4 ± 2.3 (42.8-46.7)	46 ± 2.4 (44-48.1)	42.2 ± 2.3 (40.8-44.8)	43.7 ± 3 (40.1-45.2)*	43.6 ± 1.7 (42.2-45.9)	43.8 ± 3.3 (41.1-46.7)	43.3 ± 1.7 (40.3-45.9)	43.9 ± 3.9 (40.2-46.8)

Data are presented as mean ± SD (95% CI). Note: SJ, Squat Jump; CMJ, Counter Movement Jump; DJ, Drop Jump; RM, repetition maximum; a.u., arbitrary units; LT, lower-trained group; HT, higher-trained group; *, significant differences between moments compared to pre-test; bold highlight, significant differences between all-time points comparing HT and LT.