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Physiological adaptations following a four-week of high-intensity functional training

Fiziološka adaptacija za vreme funkcionalnog treninga visokog intenziteta u trajanju od četiri nedelje

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Abstract

Background/Aim. High-Intensity Functional Training (HIFT) is a popular mixed-modal program that utilizes both resistance and aerobic based exercises. The aim of this study was to examine the physiological effects of the HIFT programing on physically active men (10) and women (10) over a four-week period through the measure of the aerobic capacity, anaerobic capacity, and maximal weight lifted. **Methods.** The participants first completed a maximal oxygen consumption (VO_2max) test. After 48-hours of rest, the subjects completed the anaerobic capacity test via the Wingate protocol. Following the Wingate test, the subjects performed a 1-repetition maximum test for squat, snatch and clean at the offsite training location. After the pre-measurements were obtained, the subjects entered a four-week the HIFT intervention and returned to the lab for all post-measurements. **Results.** Significant improvements were observed in male and female: VO_2 max (Pre: 46.7 ± 2.6, 33.7 ± 1.7 mL/kg/min; Post: 49.0 ± 3.0, 35.0 ± 1.8 mL/kg/min), Peak Wingate Power (Pre: 1206 ± 106, 708 ± 44 W; Post: 1283 ± 88, 809 ± 38 W) Mean Wingate Power (Pre: 680 ± 46, 704 ± 48 W; Post: 434 ± 15, 458 ± 18 W; $p < 0.05$), back squat (Pre: 128.8 ± 8.8 kg, 44.1 ± 6.8 kg; Post: 142.7 ± 9.8, 54.3 ± 6.2 kg) clean (Pre: 82.5 ± 6.2, 24.1 ± 3.4 kg; Post: 92.7 ± 5.8, 33.2 ± 3.3 kg) and snatch (Pre: 59.3 ± 4.4, 20.9 ± 1.7 kg; Post: 69.1 ± 5.3, 25.0 ± 2.3 kg; $p < 0.05$), respectively. No gender influence on interaction was observed over time ($p > 0.05$). **Conclusion.** The HIFT demonstrated the rapid physiological improvements in strength, aerobic and the anaerobic capacity following a four-week intervention in the physically active participants.

Key words:
exercise; exercise test; adaptation, physiological; oxygen consumption.

Apstrakt

Uvod/Cilj. Funkcionalni trening visokog intenziteta (FTVI) je popularni program mešanih modusa koji koristi i vežbe otpora i aerobne vežbe. Cilj studije bio je ispitivanje fizioloških efekata FTVI programa na fizički aktivne muškarce (10) i žene (10) tokom perioda od četiri nedelje merenjem aerobnog kapaciteta, anaerobnog kapaciteta i maksimalne podignute težine. **Metode.** Učesnici u studiji prvo su završili test maksimalne potrošnje kiseonika (VO_2). Nakon odmora od 48 sati, učesnici su završili test anaerobnog kapaciteta po Wingate protokolu. Po istom protokolu učesnici su uradili test sa jednim maksimalnim ponavljanjem za čučanj, podizanje terata do nivoa deltoidnih mišića i izbačaj naglim trzajem na drugoj lokaciji za trening. Nakon prethodnih merenja, učesnici su pristupili FTVI testu u trajanju od četiri nedelje, nakon čega su urađena ponovna merenja. **Rezultati.** Značajno poboljšanje VO_2 max ustanovljeno je i kod muškarada i kod žena (pre: 46,7 ± 2,6, 33,7 ± 1,7 mL/kg/min; posle: 49,0 ± 3,0, 35,0 ± 1,8 mL/kg/min), Maksimalna Wingate snaga (pre: 1206 ± 106, 708 ± 44 W; posle: 1283 ± 88, 809 ± 38 W); Srednja Wingate snaga (pre: 680 ± 46, 704 ± 48 W; posle: 434 ± 15, 458 ± 18 W; $p < 0,05$). Zadnji čučanj (pre: 128,8 ± 8,8 kg, 44,1 ± 6,8 kg; posle: 142,7 ± 9,8, 54,3 ± 6,2 kg). Podizanje tereta do nivoa deltoida (pre: 82,5 ± 6,2, 24,1 ± 3,4 kg; posle: 92,7 ± 5,8, 33,2 ± 3,3 kg) i izbačaj naglim trzajem: (pre: 59,3 ± 4,4, 20.9 ± 1,7 kg; posle: 69,1 ± 5,3, 25,0 ± 2,3 kg; $p < 0,05$). Nije ustanovljena interakcija uticaja pola tokom vremena ($p > 0,05$). **Zaključak.** FTVI je pokazao brzo fiziološko poboljšanje u snazi, aerobni i anaerobni kapacitet tokom četiri nedelje kod fizički aktivnih učesnika.

Ključne reči:
vežbanje; vežbanje, testovi; adaptacija, fiziološka; kiseonik, potrošnja.

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Introduction

In recent years there has been a growing interest towards the non-traditional exercise programs that involve the high-intensity bouts and require a lower time commitment. Additionally, these programs do not focus on specific aspects of fitness, but rather on a broad focus towards the general preparedness. The aforementioned programs are commonly referred to as High-Intensity Functional Training (HIFT). These include the programs like Insanity, P90x®, and CrossFit®. The unique approach to the HIFT programming is the various uses of exercise modalities, ranging from Olympic weightlifting, to the bodyweight calisthenics/gymnastic movements, with an emphasis on improving the capacity to perform large amounts of work in short periods of time. However, despite the recent trends in popularity toward HIFT like training [1] there are little evidence regarding the efficacy of this application on markers of fitness and performance in currently active individuals.

Various acute adaptations occur during the onset of a new exercise program when applied to untrained individuals. Alterations in strength can occur as early as two weeks [2] while alterations in the aerobic capacity (i.e. VO_{2max}) can occur as rapidly as six days [3]. This is commonly reported to be due to alterations in the neuromuscular system as well as oxygen related alterations in cells [2, 4]. However, when beginning a new exercise program in individuals who are already physically active, alterations and adaptations occur less rapidly. Due to the reduction in adaptation following chronic training, research continually examines the efficacy of the exercise programs over longer durations (i.e., 8, 12, 16-weeks). Several studies examining this time period have shown that both aerobic and strength based interventions result in positive alterations in body composition [5, 6] while the improvements in performance markers such as muscular strength, anaerobic and the aerobic capacity also occur in the variously trained populations [7–9].

Limited information is available on the acute adaptations to a new exercise program for individuals who are already physically active. Furthermore, the advocates of the HIFT programs purport gains and early physiological adaptations for those who participate [9, 10]. However, the acute adaptations to HIFT training have yet to be reported for individuals who are already physically active. The acute responses to HIFT in the physically active population would be beneficial for those prescribing this style in order to better assess and track improvements in clients and participants. Therefore, the purpose of this study was to determine the changes in the aerobic capacity, anaerobic capacity and 1-repetition maximum (RM) in back squat, clean and snatch, following the four-week HIFT program in physically active men and women.

Methods

Procedures

All participants reported to the Exercise Physiology Laboratory for the pre and post intervention testing, which consisted of two laboratory visits 48-hours apart. During the first visit, each subject signed the informed consent and completed a health history questionnaire. The participants then completed a maximal oxygen consumption (VO_{2max}) exercise test on a treadmill using a graded exercise protocol. The participants returned to the lab 48-hours later for the anaerobic capacity measures via the 30-second Wingate protocol. Following this measure, the participants made an appointment at a local CrossFit® affiliate and began their four-week intervention. During the first week of the acclimation period, the participants were taught a proper exercise technique and then performed a 1-RM test for squat, snatch and clean at the CrossFit® affiliate prior to the start of the four-week intervention. Following the four-week intervention, the participants returned to the laboratory for the aerobic and the anaerobic capacity testing and to the affiliate for the 1-RM testing.

HIFT intervention

The HIFT intervention chosen for this study was CrossFit®. Following the first two lab visits (i.e., after the aerobic and anaerobic capacity testing), the participants made an appointment at a local CrossFit® box affiliate where they would be instructed by a certified instructor and exercise science graduate. All participants began an introductory week to learn the basics of HIFT. The participants were provided with a full group class schedule for the next four weeks. The participants were informed they could attend as many classes per week with no restrictions, however a minimum of three days per week was required in order to remain in the study. The participants trained with the normal HIFT classes performed the workouts as prescribed by the head trainer of the affiliate. A typical class would start with a warm-up, a strength/power component, then a HIFT bout ranging from 7–25 minutes in duration. The participants were instructed and encouraged to modify each workout as needed. Following the four-weeks of training, each subject performed the 1-RM tests again under the same supervision as well as the VO_2 max, and Wingate testing, with each bout separated by at least 48 hours.

Participiants

Twenty participants (10 male, 10 female) were recruited for the current study. The participants' characteristics are shown in Table 1.

Table 1

Subject characteristics

Parameters	Male	Female
Number	10	10
Age (years), mean ± SD	26.6 ± 1.9	28 ± 2.0
Height (cm), mean ± SD	178 ± 2.3	167.5 ± 1.5
Weight (kg), mean ± SD	90.5 ± 5.8	72.2 ± 4.8
% Body Fat, mean ± SD	17.7 ± 2.0	23.7 ± 2.1

SD – Standard Deviation.

All participants were classified as recreationally trained by self-identifying as currently participating in at least 30-bouts of the planned physical activity for at least 30-minutes three times per week for at least the last 90-days. Additionally, all participants needed to participate both in the aerobic and weight training activities. None of the participants had the previous HIFT experience or reported any colds, sicknesses, or orthopedic conditions that could limit exercise participation. This study was approved the Institutional Review Board of the host university prior to recruitment and data collection.

Maximal exercise capacity, strength and anthropomorphic measurements

Aerobic capacity was determined through a graded exercise test; expired gases were analyzed by the True 1 analyzing system calibrated to known gases. Heart rate (Polar monitors) was obtained during the test. Each participant performed a 3–5 minute warm-up at a self-selected speed. The participants then breathed through a one-way valve, which enabled expired gases to be processed by the True 1 analyzing system. The participants started the test at a self-selected running speed at 0% grade. The grade was increased 2% every 2-minutes until the VO_2 leveled off or the subject stopped the test (8–10 minutes) [11]. All participants attained their age predicted maximal heart rate (HR) ± 10 bpm, reported Ratings of Perceived Exertion (RPE) > 19 on the Borg scale during the last stage of the test and had the Respiratory Exchange Ratio (RER) > 1.10.

The anaerobic capacity was obtained approximately 48-hours following the first visit. For the testing, the participants returned to the laboratory to have their peak and mean power measured using the Wingate test. Briefly, using the Lode cycle ergometer, the subjects pedaled at a self-selected moderate intensity for 5-minutes as a warm-up. Then, the participants performed the Wingate test against resistance equal to 7.5% of their bodyweight on a electronically controlled braking bike and had both their mean and peak power measured.

Muscular strength assessment occurred after a one-week introduction to a proper form and techniques in HIFT. After the one-week introduction, the subjects performed a 1-RM in the following order on the same day: snatch, clean and back squat. The progression was self-selected and the participants were allowed unlimited attempts at every weight and they achieved their 1-RM within 4 attempts, with no time limit provided. Each of the attempts were supervised by the certified HIFT instructor as well as the Principal Investigator (PI), a certified strength and conditioning specialist (CSCS).

Statistical analysis

All data were analyzed by the SPSS version 24 (IBM, New York, NY). Prior to the data analysis, the variables were analyzed by the Shapiro-Wilk test in order to determine normality of the data distribution. The effect of the intervention was determined using a repeated measure 2 × 2 ANOVA (time by gender) and a statistical significance was set at $p < 0.05$. If there was an interaction effect, the Scheffe post-hoc test was utilized to identify differences.

Results

All 20 participants completed the study. Compliance was 100%, as all subjects attended the four-week classes for a minimum of three times a week. There were no injuries reported to the investigators, or to the trainers. The Shapiro-Wilk test demonstrated that the sprint data was normally distributed for all conditions. Following the 4 weeks of training, all measured variables showed the significant main effects in both genders. Table 2 shows the laboratory measures. The participant's VO2 max demonstrated a main time effect (p = 0.016) and no time × gender effect (p = 0.415). The Peak Wingate Power test demonstrated the main time effect (p = 0.010) and no time × gender effect (p = 0.712). The Mean Wingate Power demonstrated a main time effect (p = 0.026) and no time × gender effect (p > 0.999). Table 3 shows the 1 RM measures. The participant's back squat demonstrated a main time effect (p < 0.001) and no time × gender effect (p = 0.327). The participant's clean demonstrated a main time effect (p < 0.001) and no time × gender effect (p = 0.648). The participant's snatch demonstrated a main time effect (p < 0.001) and a main time × gender effect (p = 0.042).

Table 2

Laboratory Performance: Aerobic & Anaerobic

Test	Male	Confidence interval	*p* value	Effect size	Female	Confidence interval	*p* value	Effect size
VO_2 Max Pre (mL/kg/min)	46.7 ± 2.6	± 1.61			33.7 ± 1.7	± 1.05		
VO_2 Max Post (mL/kg/min)	49.0 ± 3.0*	± 1.86	0.032	-0.2419	35.0 ± 1.8	± 1.12	0.239	0.3480
Wingate Peak Power Pre (W)	1206 ± 106	± 65.7			708 ± 44	± 27.27		
Wingate Peak Power Post (W)	1283 ± 88*	± 54.54	0.015	-0.3675	809 ± 38*	± 23.55	0.025	-0.7755
Wingate Mean Power Pre (W)	680 ± 46	± 28.51			434 ±15	± 29.75		
Wingate Mean Power Post (W)	704 ± 48*	± 9.3	0.018	+0.9634	458 ± 18*	± 11.16	0.047	+0.9592

Results are given as mean ± standard deviation.
*** significant time main effect; VO_2 – maximum oxygen consumption.**

Table 3

Laboratory Performance: Strength

Test	Male	Confidence interval	*p* value	Effect size	Female	Confidence interval	*p* value	Effect size
Back Squat Pre (kg)	128.8 ± 8.8	± 5.45			44.1 ± 6.8	± 4.21		
Back Squat Post (kg)	142.7 ± 9.8*	± 6.07	0.0006	-0.5980	54.3 ± 6.2*	± 3.84	0.008	-0.6168
Clean Pre (kg)	82.5 ± 6.2	± 3.84			24.1 ± 3.4	± 2.11		
Clean Post (kg)	92.7 ± 5.8*	± 3.59	0.0002	-0.6474	33.2 ± 3.3*	± 2.05	0.0007	-0.8052
Snatch Pre (kg)	59.3 ± 4.4	± 2.73			20.9 ± 1.7	± 1.05		
Snatch Post (kg)	69.1 ± 5.3*#	± 3.28	0.002	-0.7092	25.0 ± 2.3 *#	± 1.43	0.004	-0.7118

Results are given as mean ± standard deviation.
***significant time main effect; # main effect for time × gender.**

Discussion

The purpose of this study was to determine the changes in the aerobic capacity, anaerobic capacity and 1-RM in back squat, clean and snatch following a four-week HIFT program of the physically active men and women. The primary findings demonstrated the time-dependent improvements in the aerobic capacity, anaerobic capacity, squat, clean and snatch. A gender-by-time effect was only observed in the pre and post snatch measures. Further points of consideration are provided below.

Markers of strength

The markers of muscular strength examined in this study were the Squat, Clean and Snatch. Following the HIFT intervention, the significant strength adaptations in each marker occurred, suggesting that the four-week time period was sufficient enough to elicit changes in the physically active participants. Acute strength adaptations are common among sedentary individuals beginning a new exercise program due to neural adaptations (e.g., synchronization and recruitment of additional motor units, increased neural drive, etc.). However, these adaptations are less observed in those who are already physically active. For instance, Ahtiainen et al. [7] examined the difference in strength adaptation between the trained and untrained participants where the significant alterations were observed only at 14 weeks and 10 weeks later than the observation made in the current study. It is important to note that even though the participants in the current study were physically active, their experience and technique associated with the examined markers (i.e., power clean and snatch) were limited and therefore a likely mechanism for the observed improvements following the four-week intervention.

Neuromuscular adaptation is commonly attributed to the early improvements in strength [2] and is greatly related to the learning and coordination of the muscle groups as it relates to the specificity of training [12]. This notion is supported by a 60-day unilateral strength training study performed by Narici et al. [13], which yielded an approximate 9% of the improvement in the maximal voluntary contraction with no improvements in the cross-sectional area; however, an approximate 25% of the improvement in the neuromuscular activity (via the integrated electromyographic activity) occurred. An alternative explanation for the observed improvements in strength within this study is early skeletal muscle hypertrophy. This is a rare occurrence; however, there are a few documented cases of the early adaptive hypertrophy. For example, the significant gains in strength and hypertrophy were observed in the recreationally trained participants by the third week of a 35-day high-intensity resistance training study [14]. It is important to note that the examination of the hypertrophic response to training is outside the scope of this study, but the notion presents an alternative explanation for the significant gains in strength observed during the four-week training period.

Aerobic performance

The HIFT style programming is not traditionally prescribed for the improvements in the aerobic performance. However, a recent research has shown increases in the oxygen consumption following a high-intensity training [15], and therefore, garnered more interest in the scientific community. For instance, Helgerud et al. [16], examined the effects of four different types of exercise modalities over the eight-week period in the aerobically trained males; two of the programs were of the aerobic type, continuous, and of long duration (i.e., 25–45 min between 70% and 85% HR_{max}) while the other two were the high-intensity intervals (i.e., 47 repetitions of 15-sec activity at 90%–95% HR_{max}, and 15 sec recovery at 70%, vs. four 4-minute 90%–94% and 3-minute recovery at 70% HR_{max}) [16]. Upon the completion of eight weeks, only those who participated in the high-intensity groups reported the significant increases in VO_{2max}: (pre: 60.5 ± 5.4 vs. post: 64.4 ± 4.4 mL/kg/min^{-1}) / (pre: 55.5 ± 7.4 vs. post: 60.4 ± 7.3 mL/kg/min^{-1}), respectfully [16]. Additionally, six weeks of a high-intensity cycling interval training was enough to elicit a 7 mL/kg/min^{-1}, which was comparable to 5 mL/kg/min^{-1} observed following the aerobic training protocol [9]. The findings of the improved VO_{2max} following the HIFT intervention in the current study support the literature in that that a high-intensity based training is an effective mode for the improved VO_2.

Another important consideration is the time frame of the current study. Though it is well established that the aerobic capacity improves following multiple weeks of training (i.e., ≥ eight-weeks) [7, 16, 17], there is little empirical evidence regarding the training protocols less than eight-weeks ?of training? in the physically active participants. In a study by Burgomaster et al. [18], the researchers observed an almost the two times greater improvement in muscle endurance after two-weeks of the high-intensity sprint training in the physically active participants. Despite this, no improvements in the oxygen consumption was observed following the two-week intervention. Similarly, the seven-day high-intensity training (HIT) overload training study was performed on a competitive cyclist and found the significant improvements in time trial performance, despite no observed change in the physiological factors [19]. Conversely, the two-week sprint cycling training protocol improved peak oxygen consumption by 7% in the sedentary and overweight participants [20]. The two-week sprint cycling study, in conjunction with the current findings, supports the notion that the rapid improvement in aerobic adaptation can occur following HIFT. Currently, there is a limited number of studies that provide insight into the mechanisms responsible for the early aerobic adaptation following HIFT-like programming. Due to the conflicting results within the current literature, further research in this area is required.

Though it is outside the scope of the current study, several physiological factors may have played a role in the rapid improvement in the aerobic performance. A commonly observed adaptation following HIT is an increase in peripheral vascular structure and function. This results in the improved delivery of O_2 to the tissues and subsequently improved the a-vO_2 difference [21]. However, it is unlikely that the vascular structure increased during the four-weeks of HIFT; rather, it is more probable that an improvement of vascular function and control contributed to the observed improvement in VO_{2max}. An important distinction to make between HIT and HIFT is the modality of the exercise being used. The most of the aerobic and HIT training protocols use a single modality such as running or cycling [9, 20, 22], while the HIFT training incorporates aerobic, anaerobic and resistance- based exercise all in one workout. Many of the exercise movements in HIFT include upper body movements (e.g., push-press, push-up, pull-up, etc.). The reason this is important to note is the presence of the pressor reflex, which has been shown to more rapidly elevate the HR and place more stress on hemodynamics [8], thus presenting a potential mechanism for adaptation.

Anaerobic markers

Each participants in the study performed the Wingate Test before and after the four-week HIFT intervention. The significant increases in the post-peak and post-mean power output were observed both in males and females. These results support the hypothesis that the improvements in the anaerobic performance would occur following the short four-week intervention. It is well-established that the participation in the HIT-like programming results in the anaerobic improvements (i.e., peak power and mean power) [15, 23]. For instance, the untrained individuals showed improvements in the anaerobic performance (5%–28%) following the HIT training ranging from 2 to 14 weeks [23]. Conversely, a two-week sprint interval training program in the physically active participants improved the anaerobic performance, which was suggested to happen because of the improved cellular buffering systems [22]. This supports the findings of the current study, which observed an increase of the mean power output 3.5% (male) and 5.5% (female) and peak power output 6.4% (male) and 14.1% (female).

Though the participants of this study were physically active, they were not regularly engaged in the high-intensity exercise, and thus, they were more liable to respond to the HIFT training through the principle of the anaerobic overload. Therefore, it is possible that these "physically active subjects" behaved similar to the untrained person regarding the anaerobic training. The general postulation regarding adaptation is related to the improvements in the muscle buffering capacity [23], improved the muscle quality [21] and glycogen stores [21, 22].

Study Limitations

Though this study was a novel attempt to examine the influences of a four-week HIFT intervention of physiological markers of fitness in physically active individuals, it was not without its limitations. The sample size was a limiting factor of this study, though the overall effects were great enough to observe significant changes, a larger data set would provide better insight into the influences of this intervention. Furthermore, future studies should include multiple time points that span a longer period of time. The current study provides a needed understanding of the early influences of a HIFT intervention; however, a longer timeline would allow for a better understanding of the rate and degree of physiological adaptation. Lastly, the biomarkers of health such as lipid profile and glucose regulation should be examined pre and post HIFT intervention to provide a more holistic approach to examining adaptation.

Conclusion

HIFT demonstrated the rapid physiological improvements in muscular strength, aerobic capacity and anaerobic capacity, following the four-week intervention in the physically active participants. Given the starting training status of the participants and the relatively short duration of the intervention, these findings demonstrate HIFT to be a unique and an effective method of training to induce the overall markers of fitness.

R E F E R E N C E S

1. *Thompson W*. Worldwide Survey of Fitness Trends For 2015: What's Driving the Market. ACSM's Health Fitness J 2014; 18(6): 8–17.
2. *Sale DG*. Neural adaptation to resistance training. Med Sci Sports Exerc 1988; 20(5 Suppl): S135–45.

3. *Goodman JM, Liu PP, Green HJ.* Left ventricular adaptations following short-term endurance training. J Appl Physiol (1985). 2005; 98(2): 454–60.
4. *Powers SK, Jackson MJ.* Exercise-induced oxidative stress: Cellular mechanisms and impact on muscle force production. Physiol Rev 2008; 88(4): 1243–76.
5. *Keating SE, Machan EA, O'Connor HT, Gerofi JA, Sainsbury A, Caterson ID,* et al. Continuous exercise but not high intensity interval training improves fat distribution in overweight adults. J Obes 2014; 2014: 834865.
6. *Osei-Tutu KB, Campagna PD.* The effects of short- vs. long-bout exercise on mood, VO2max, and percent body fat. Prev Med 2005; 40(1): 92–8.
7. *Ahtiainen JP, Pakarinen A, Alen M, Kraemer WJ, Häkkinen K.* Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. Eur J Appl Physiol 2003; 89(6): 555–63.
8. *Collins MA, Cureton KJ, Hill DW, Ray CA.* Relationship of heart rate to oxygen uptake during weight lifting exercise. Med Sci Sports Exerc 1991; 23(5): 636–40.
9. *Tabata I, Nishimura K, Kouzaki M, Hirai Y, Ogita F, Miyachi M,* et al. Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max. Med Sci Sports Exerc 1996; 28(10): 1327–30.
10. *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) 2007; 102(4): 1439–47.
11. *McKenzie MJ, Goldfarb A, Garten RS, Vervaecke L.* Oxidative stress and inflammation response following aerobic exercise: Role of ethnicity. Int J Sports Med 2014; 35(10): 822–7.
12. *Folland JP, Williams AG.* The adaptations to strength training�: morphological and neurological contributions to increased strength. Sports Med 2007; 37(2): 145–68.
13. *Narici MV, Roi GS, Landoni L, Minetti AE, Cerretelli P.* Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps. Eur J Appl Physiol Occup Physiol 1989; 59(4): 310–9.
14. *Seynnes OR, de Boer M, Narici MV.* Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. J Appl Physiol (1985) 2007; 102(1): 368–73.
15. *Gibala MJ, McGee SL.* Metabolic adaptations to short-term high-intensity interval training: A little pain for a lot of gain? Exerc Sport Sci Rev 2008; 36(2): 58–63.
16. *Helgerud J, Høydal K, Wang E, Karlsen T, Berg P, Bjerkaas M,* et al. Aerobic high-intensity intervals improve VO2max more than moderate training. Med Sci Sports Exerc 2007; 39(4): 665–71.
17. *Tjønna AE, Leinan IM, Bartnes AT, Jenssen BM, Gibala MJ, Winett RA,* et al. Low- and high-volume of intensive endurance training significantly improves maximal oxygen uptake after 10-weeks of training in healthy men. PloS One 2013; 8(5): e65382.
18. *Burgomaster KA, Hughes SC, Heigenhauser GJ, Bradwell SN, Gibala MJ.* Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. J Appl Physiol (1985) 2005; 98(6): 1985–90.
19. *Clark B, Costa VP, O'Brien BJ, Guglielmo LG, Paton CD.* Effects of a seven day overload-period of high-intensity training on performance and physiology of competitive cyclists. PloS One 2014; 9(12): e115308.
20. *Whyte LJ, Gill JM, Cathcart AJ.* Effect of 2 weeks of sprint interval training on health-related outcomes in sedentary overweight/obese men. Metab Clin Exp 2010; 59(10): 1421–8.
21. *Gibala MJ, Little JP, MacDonald MJ, Hawley JA.* Physiological adaptations to low-volume, high-intensity interval training in health and disease. J. Physiol (Lond) 2012; 590(5): 1077–84.
22. *Gibala MJ, Little JP, Essen M, Wilkin GP, Burgomaster KA, Safdar A,* et al. Short-term sprint interval versus traditional endurance training: Similar initial adaptations in human skeletal muscle and exercise performance. J Physiol (Lond) 2006; 575(Pt 3): 901–11.
23. *Jabbour G, Iancu HD, Paulin A.* Effects of High-Intensity Training on Anaerobic and Aerobic Contributions to Total Energy Release During Repeated Supramaximal Exercise in Obese Adults. Sports Med Open 2015; 1(1): 36.

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