

ACUTE PHYSIOLOGICAL RESPONSES DURING CROSSFIT® WORKOUTS

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ABSTRACT

The aims of the present study were to describe the acute physiological and perceptual response of two typical CrossFit® workouts of the day (WODs) and to investigate whether the physical demands of these WODs meet the criteria laid down by the ACSM to improving and maintaining cardiovascular fitness in healthy adults. Methodology: ten healthy subjects (Age: 30±4.2 years) volunteered to participate in a study including laboratory incremental treadmill test and two CrossFit® WODs (e.g., “Fran” and “Cindy”). Measurements included subjects’ oxygen uptake (VO₂), heart rate (HR), blood lactate (LA) and ratings of perceived exertion (RPE). Results: significant differences ($P<0.001$; ES=1.0) were found for average VO₂ (34.4±3.5 vs. 29.1±1.1 ml·kg⁻¹·min⁻¹), %VO₂max (66.2±4.8 vs. 56.7±6.2%) and EE (318.2±32.5 vs. 121.0±38.5 kcal·min⁻¹; $P<0.001$; ES=3.8) with “Cindy” workout showing higher values, while “Fran” resulted in significantly time spent above 1 (76.0±29.7 vs. 47.7±21.4 %; $P<0.05$; ES=0.7). Conclusion: the acute physiological demands of the CrossFit® WODs analyzed meet the ACSM guidelines for energy expenditure and exercise intensity in healthy adults, although due to the high intensity of the workouts analyzed (90-95% of HRmax; LA values >10 mmol⁻¹; RPE values >8), together with the lack of research in this topic, the safety has not been defined for such programs.

Key Words: CrossFit®, workouts of the day (WODs), oxygen uptake, heart rate, blood lactate, RPE, energy expenditure

RESUMEN

Los objetivos del estudio fueron describir la respuesta fisiológica y perceptiva aguda a dos rutinas de ejercicios diarios (WODs) de CrossFit®, investigando si las exigencias físicas de éstas cumplen con los criterios establecidos por la ACSM para mejorar y mantener la aptitud cardiovascular en adultos sanos. Metodología: diez voluntarios sanos (edad: 30±4.2 años) participaron en un estudio que incluyó un test incremental maximal y dos WODs de CrossFit® (“Fran” y “Cindy”). Se midieron consumos de oxígeno (VO₂), frecuencias cardiacas (FC), lactato sanguíneo (LA) y escala de percepción del esfuerzo (RPE). Resultados: se encontraron diferencias ($P<0.001$; ES=1.0) entre los promedios de VO₂ (34.4±3.5 vs. 29.1±1.1 ml·kg⁻¹·min⁻¹), %VO₂max (66.2±4.8 vs. 56.7±6.2%) y EE (318.2±32.5 vs. 121.0±38.5 kcal·min⁻¹; $P<0.001$; ES=3.8), siendo mayores los valores obtenidos con “Cindy”; mientras el porcentaje de tiempo por encima de 1 del cociente respiratorio fue mayor en “Fran” (76.0±29.7 vs. 47.7±21.4 %; $P<0.05$; ES=0.7). Conclusiones: las demandas fisiológicas agudas de las WODs analizadas, coinciden con las directrices de la ACSM de gasto energético e intensidad del ejercicio en adultos sanos, aunque debido a la altas intensidades registradas (90-95% de la FC máx; valores LA > 10 mmol⁻¹; valores de RPE > 8), junto con la falta de investigación, hace que los criterios de seguridad estén por definir.

Palabras clave: CrossFit®, rutina de ejercicio diaria, consumo de oxígeno, frecuencia cardiaca, lactato sanguíneo, RPE

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INTRODUCTION

In the last few years, there has been a dramatic increase in the number and type of activities in fitness centers that employ high intensity interval training (HIIT) as an alternative to traditional endurance training for the improvement of aerobic fitness (Gillen & Gibala, 2014). Recent research showed that HIIT provides fitness and health improvements in less time per week than traditional guidelines (Gibala & Jones, 2013; Gibala & McGee, 2008; Hood, Little, Tarnopolsky, Myslik, & Gibala, 2011; Skelly et al., 2014) (e.g., ≥ 150 minutes of moderate-intensity or ≥ 75 minutes of vigorous-intensity aerobic physical activity, and ≥ 2 days strength training, per week)(Garber et al., 2011).

Among all these new “tendencies” or activities, CrossFit® is a group-based HIIT combining aerobic and strength exercises with focus on functional (multi-joint) movements (Smith, Sommer, Starkoff, & Devor, 2013). It is characterized by workouts named “workouts of the day” (WODs) that use a wide variety of exercises, ranging from running and rowing to Olympic/power lifting (e.g., snatch, press/push press), to gymnastic movements (e.g., pull-ups, burpees, rope climbs)(Glassman, 2011). These exercises are often combined into high-intensity (e.g., self-selected) workouts that are performed in rapid, successive repetition, with limited or no recovery time (Glassman, 2011; Heinrich, Patel, O'Neal, & Heinrich, 2014). Some workouts are performed for a best time, and others are performed in the “as many rounds as possible” style using varying time domains, ranging from 10 to 20 minutes (Smith et al., 2013).

CrossFit® has gained widespread attention for several reasons: easy access to programming, a short time commitment, and higher enjoyment than traditional training (Heinrich et al., 2014). However, despite its popularity within the fitness community, limited research has been performed to document the physiological responses during CrossFit® workouts. In this regard, CrossFit® has been shown to elicit a high acute cardiovascular training response as well as significant increases in fitness levels (i.e., aerobic and anaerobic performance) (Butcher, Neyedly, Horvey, & Benko, 2015; Paine, Uptgraft, & Wylie, 2010; Smith et al., 2013). However, the great variety of CrossFit® routines (e.g., exercise types, velocity of movement, exercise intensity, muscular groups) and the lack of control during the workouts (Often, workouts are posted with a prescribed weight and repetition scheme, which can prove to be excessive for even more experienced participants (Weisenthal, Beck, Maloney, DeHaven, & Giordano, 2014)), make it difficult to understand the acute and chronic responses to these activity. Thus, the aim of the present study was to describe the acute physiological and perceptual responses of two typical CrossFit® workouts (e.g., WODs). In addition, this study investigated whether the physical demands of these WODs meet the criteria set forth by the

ACSM for improving and maintaining cardiovascular fitness in healthy adults (Medicine, 2013).

METHOD

We analyzed and described the physiological (heart rate (HR), oxygen uptake (VO_2), blood lactate (La)) and perceptual (rate of perceived exertion (RPE)) parameters during two CrossFit® workouts or WODs (e.g., “Fran” and “Cindy”). A group of healthy subjects were tested in a two-week period. The experimental design was divided into 2 parts: a laboratory test, and two WODs, separated by one week. WODs were performed at the same hour and under similar conditions (e.g., between 18-20h; temperature: 22-24°C, relative humidity 54.4–61.0% (Kestrel 4000 Pocket Weather Tracker; Nielsen Kellerman, Boothwyn, PA, USA)). Measurements began after a 5-minute standardized warm-up, which consisted of jogging around the gym, dynamic flexibility and movement simulation (e.g., the execution of the tested movements, but performed at low intensities (~60% of HR_{max}). To reduce the interference of uncontrolled variables, all the subjects were instructed to maintain their habitual lifestyle and normal dietary intake before and during the study. The subjects were told not to exercise on the day before a test and to consume their last (caffeine free) meal at least 3 hours before the scheduled test time.

Ten healthy subjects (Age: 30 ± 4.2 years; weight: 77 ± 9 kg; height: 1.76 ± 0.08 m; body mass index (BMI): 24.8 ± 2.3) volunteered to participate in the study. All subjects were recruited from and trained at a CrossFit® affiliate (“CrossFit® Elche”) and had 12 ± 2 months of training experience in CrossFit training. Before participation, all subjects were provided with written informed consent and the experimental procedures and potential risks were explained. The research committee of the University Miguel Hernandez of Elche (Spain) approved the study.

On arrival for a laboratory treadmill test, anthropometric measurements including height and weight were determined. All subjects performed a maximal exercise test on a motorized treadmill (RunMed, Technogym, Italy) to determine maximum HR (HR_{max}) and maximum oxygen uptake (VO_{2max}). The treadmill test consisted of an initial workload of $8 \text{ km}\cdot\text{h}^{-1}$ with an increase of $2 \text{ km}\cdot\text{h}^{-1}$ every 3 minutes at a constant grade of 1.5% until exhaustion (31). Respiratory gas exchange measures were taken using a breath-by-breath portable gas analyzer (K4b2, Cosmed, Rome, Italy) and recorded at 5-second intervals. HR was recorded by the K4b2 with athletes wearing a chest belt (Polar S610, Kempele, Finland). The volume calibration of the system for gas analysis was conducted before each test day, and the gas calibration was performed before each test using instructions provided by the manufacturer.

The highest 30-second mean VO_2 and HR values measured during the test were used as maximum reference values (HR_{max} and $\text{VO}_{2\text{max}}$). Criteria for determination of $\text{VO}_{2\text{max}}$ included plateau in VO_2 despite an increase in workload, respiratory exchange ratio >1.1 , and HR $>90\%$ of predicted HR_{max} .

Two popular styles of CrossFit® WODs were performed by the subjects in a randomized order, and separated by one week each. WODs were the “classic triplet” (“Fran” workout) and as many rounds as possible (or AMRAP) (“Cindy” workout) (Glassman, 2011). The classic triplet, or “Fran” for the present study, is a three round workout with the repetition scheme of 21-15-9. The workout consisted of a “thruster” (i.e., an exercise that involves the front squat and press) followed by pull-ups. All repetitions of the first exercise must be completed before beginning the next exercise. Thus, 21 thrusters and pull-ups must be completed before moving on to the round of 15, and so on. The overall goal of this type of WOD is to complete the prescribed exercises and reps as fast as possible; no rests are scheduled or required.

The second WOD was the AMRAP, or “Cindy”, for the present study. The WOD consisted in complete as many rounds as possible of 5 pull-ups, 10 push-ups, and 15 air squats in 20 minutes.

During the WODs subjects were monitored using a Cosmed K4 portable gas analyzer to measure VO_2 and to estimate the quantity of energy expended during both workouts. Subjects’ VO_2 and HR (Polar S610, Kempele, Finland) were determined breath by breath and at 5-second intervals, respectively. Both measurements were measured continuously and then averaged over the duration of each workout to determine the mean values. Energy expenditure was calculated from the VO_2 values using $5 \text{ kcal.L}^{-1} \text{ O}_2$ as the caloric equivalent (Thompson, Arena, Riebe, Pescatello, & American College of Sports, 2013). Ratings of perceived exertion were obtained using the CR10 Borg RPE scale (Foster et al., 2001). The scale was explained before the exercise. The subjects were asked: “how hard do you feel the exercise was?”. Subjects had to give ratings corresponding to their sensations during the previous exercise. RPE measurements were taken at the end of the “Fran” workout, and every 7 minutes, during the “Cindy” workout (3 values overall). Blood lactate concentrations were determined from 25 ml capillarized blood samples drawn from the earlobe and analyzed with a portable device (Lactate Scout, Senselab, Germany)(Tanner, Fuller, & Ross, 2010). For both WODs, “Fran” and “Cindy”, samples were taken before the beginning, at the end of the WOD, and during the recovery phase (at minutes 1, 3 and 5).

For statistical analyses, all results are expressed as mean \pm SD. Standard statistical methods were used to calculate the mean and standard deviation of parameters analysed. The results of normality and homogeneities of variance were tested using Kolmogorov-Smirnov test (K-S). In order to analyse routine

differences for protocol design, a one way ANOVA was employed. Statistical significance was accepted when $P < 0.05$. The criteria to interpret the magnitude of the ES were: 0.0–0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large and >2.0 very large (Hopkins, 2000). All data were analysed using the statistical package SPSS 20.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Average (\pm SD) VO_{2max} and HR_{max} during the treadmill test were 52.2 ± 7.0 $ml \cdot kg^{-1} \cdot min^{-1}$ and 187.6 ± 5.0 $beats \cdot min^{-1}$, respectively. The descriptive values corresponding to the different workouts are presented in Table 1. Maximal and mean HR did not differ significantly between “Cindy” and “Fran” workouts (Small ES for both, HR (0.3) and $\%HR_{max}$ (0.5)). Significant differences ($P < 0.001$) and moderate ES ($=1.0$) were found for average VO_2 and $\%VO_{2max}$, with “Cindy” workout showing higher values. Moreover, EE was significantly higher in “Cindy” workout ($P < 0.001$), with very large ES ($=3.8$). Respiratory exchange ratio did not show differences between workouts. However, “Fran” resulted in significantly higher time spent above RER 1 ($P < 0.05$; Moderate ES = 0.7), while “Cindy” resulted in significantly greater time below 1 ($P < 0.05$; Moderate ES = 0.8). No significant differences were found between workouts in LA (pre and post-test measures) and RPE values.

TABLE 1
Physiological and perceptual responses obtained during CrossFit WODs.

	Cindy	Fran	Effect Size (ES)
HR_{av} ($beats \cdot min^{-1}$)	182.2 ± 6.6	179.0 ± 8.4	0.3
$\%HR_{max}$	97.4 ± 2.4	95.4 ± 3.0	0.5
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	$34.4 \pm 3.5^{**}$	29.1 ± 1.1	1.0
$\%VO_{2max}$	$66.2 \pm 4.8^{**}$	56.7 ± 6.2	1.0
% Time RER below 1	$52.3 \pm 21.4^*$	25.2 ± 31.1	0.7
% Time RER above 1	47.7 ± 21.4	$76.0 \pm 29.7^*$	0.8
EE total ($kcal \cdot min^{-1}$)	$318.2 \pm 32.5^{**}$	121.0 ± 38.5	3.8
LA-pre ($mmol \cdot l^{-1}$)	4.0 ± 1.3	4.0 ± 1.3	0.02
LA-post ($mmol \cdot l^{-1}$)	14.5 ± 3.2	14.0 ± 3.3	0.1
RPE	8.0 ± 0.9	8.4 ± 0.9	0.3

* Significant differences between workouts ($P < 0.05$), ** ($P < 0.001$); HR_{av} : Average heart rate; $\%HR_{max}$: Percentage of HR_{max} ; VO_2 : Oxygen uptake; $\%VO_{2max}$: Percentage of maximum VO_2 ; RER: respiratory exchange ratio; LA: blood lactate; RPE: Rate of perceived exertion

Figure 1 shows the percentage of time spent by participants in the different HR categories during the workouts. Subjects spent $42.2 \pm 24.0\%$ and $29.3 \pm 17.2\%$ of the training time at intensities above 91% of HR_{max} , during “Cindy” and “Fran” workouts, respectively, with individual ranges varying from $\sim 10\%$ to 76% of the total time during the “Cindy” workout, and from $\sim 27\%$ to 52%

during the “Fran” workout. Moreover, during the “Cindy” workout the time spent at intensities between 81-90% of HR_{max} was significantly higher than the rest of intensities ($P < 0.05$; ES= 0.84 to 0.92). Comparing both workouts, significant differences were found at intensities between 81-90% of HR_{max} (e.g., $28.3 \pm 17.2\%$ and $19.1 \pm 9.3\%$ for “Cindy” and “Fran”, respectively; $P < 0.05$; ES=0.42).

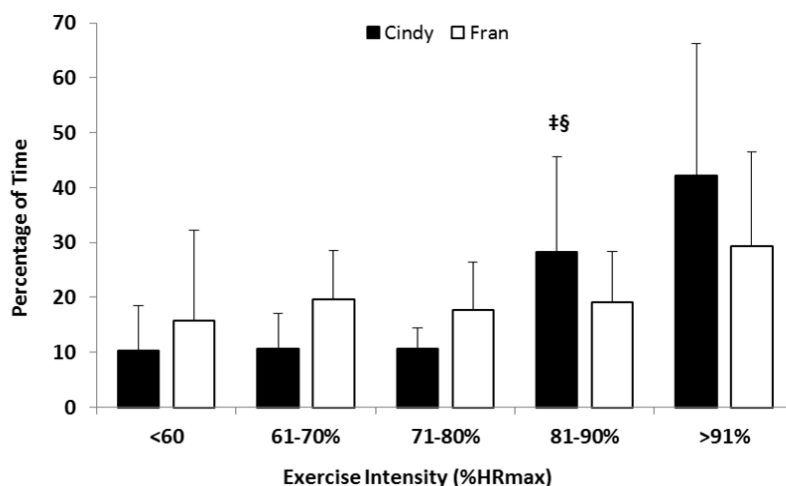


FIGURE 1: Percentage of time spent by participants in the different heart rate (HR) categories during the WODs. # Significant differences ($P < 0.05$) using adjustment for multiple comparisons of Bonferroni from 71-80%. § Significant differences ($P < 0.05$) between routines.

DISCUSSION

Although CrossFit® is becoming a popular training program there is a lack of research concerning the acute or medium-term effects of this type of training. The aims of the present study were to describe the acute physiological and perceptual responses of two typical CrossFit® WODs (e.g., “Cindy” and “Fran”), and to investigate whether the physical demands of these WODs meet the criteria suggested by the ACSM for improving and maintaining cardiovascular fitness in healthy adults. Results showed that both WODs analyzed here are high intensity workouts achieving near maximal physiological (e.g., 95-95% of HR_{max}) and perceptual levels (e.g., RPE values > 8), with significant differences found comparing WODs (e.g., VO₂, %VO_{2max} and EE higher in the “Cindy”, and “Fran” resulted in significantly higher percentage of time spent above RER 1). Taken together, the acute physiological demands of the the CrossFit® WODs

analyzed here meet the ACSM guidelines for energy expenditure and exercise intensity in healthy adults (Garber et al., 2011).

The ACSM, to promote and maintain health in adults, recommends engaging in moderate-intensity aerobic physical activity (i.e., intensities of 40–60% of VO_{2max} ; 60–75% of HR_{max} for a minimum of 30 min per day, 5 days per week or vigorous-intensity aerobic activity (i.e., 60% of VO_{2max} ; 75% HR_{max}) for a minimum of 20 min per day, 3 days per week (Garber et al., 2011). In this regard, the participation in vigorous-intensity activity or high-intensity activity has been shown as more effective in improving fitness levels in less time per week than moderate-intensity (Gibala & McGee, 2008). Acute physiological demands reported in both WODs represented approximately 95% of HR_{max} and 55-65% of VO_{2max} . Thus, both WODs achieved the recommended stimulus for effective initiation of cardiovascular adaptations and conditioning as prescribed by the ACSM.

The ACSM guidelines recommend that an exercise routine should elicit an expenditure of 300 kcal and be performed for a minimum of 3 days per week for total body mass and fat weight loss (Garber et al., 2011). An expenditure of 200 kcal is also recommended if the frequency is more than 3 times per week. Data in this study indicate a moderate caloric expenditure for this mode of exercise, although relative duration of the WODs was small (~120 to ~320 kcal·min⁻¹ for ~9 and 20 minutes of exercise, during the “Fran” and “Cindy” WODs, respectively). Since there is a lack of research analysing the acute demands of CrossFit® routines, comparison of present results are difficult. Only one previous study investigated the effect of a 10-week CrossFit® program on body composition and VO_{2max} values in healthy adults of various levels of fitness (23 males, 20 females)(Smith et al., 2013). Results showed significant improvements in VO_{2max} and body composition in subjects of both genders across all levels of fitness. However, comparisons are not possible as relative intensities of the different WODs used are not reported. Previous research showed that EE during resistance exercise sessions (consecutive multiple-set or circuits; from 20 to 60 min) resulted in a wide range of EE values, from 64 to 534 kcal (Hunter, Wetzstein, Fields, Brown, & Bamman, 2000; Meirelles & Gomes, 2004; Thornton & Potteiger, 2002). One of the suggested benefits of CrossFit® workouts is that require much less time spent training than traditional aerobic/resistance exercise (Smith et al., 2013), as it includes a lack of prescribed rest period, focuses on sustained high power output, and uses multiple joint movements. In this regard, previous studies also indicate that the acute metabolic (e.g., VO_2 , EE) responses are higher during training sessions using large muscle-mass exercises (e.g., Squats, deadlift, lunges)(Mazzetti et al., 2011; Ratamess et al., 2014; Robergs, Gordon, Reynolds, & Walker, 2007). On the basis of the responses of the subjects to the WODs analyzed here, the

participation in a 3 to 5-day per week CrossFit® training would contribute to long-term weight management (Myers et al., 2002). This has important ramifications because weight loss and fat reduction are often reasons that motivate people to exercise (Stiegler & Cunliffe, 2006).

Analyzing the acute responses of the WODs analyzed in the present study, significant differences were found. Physiological responses showed that “Cindy” workout lead to significantly higher VO_2 , $\% \text{VO}_{2\text{max}}$ and EE than “Fran”. This seems to be related to the WODs duration, as “Cindy” entailed completing as many rounds as possible in 20 min, while “Fran” entailed completing the prescribed exercises and repetitions as fast as possible (~9 min). This could also be related to the differences found in the time spent at different RER, with “Fran” resulted in significantly higher time spent above 1, highlighting the high anaerobic profile of this WOD. This is also supported by the high LA levels reported at the end of the workout ($14.0 \pm 3.3 \text{ mmol}\cdot\text{l}^{-1}$), which were still elevated after 5 min of recovery ($13.6 \pm 1.6 \text{ mmol}\cdot\text{l}^{-1}$). Although the “Cindy” routine lead to significantly higher time spent at RER below 1, post-LA values were similar to “Fran” ($14.5 \pm 3.2 \text{ mmol}\cdot\text{l}^{-1}$), with values also high after 5 min of recovery ($11.7 \pm 2.8 \text{ mmol}\cdot\text{l}^{-1}$). Moreover, RPE responses to both WODs were similar, with maximal average values, rated as very hard (8-9). Again, the lack of studies regarding acute demands of CrossFit® makes comparisons not possible. However, LA and RPE values are in line with previous research analysing long and short HIIT protocols (Buchheit & Laursen, 2013). Therefore, participants of CrossFit® should strive to maintain a good understanding of their limitations during exercise in order to cope with high intensity and repetitive exercise bouts.

In conclusion, to the best of our knowledge, this is the first study analyzing the acute physiological and perceptual responses of two typical CrossFit® WODs (e.g., “Cindy” and “Fran”). Results showed that both WODs could be characterized as high intensity workouts, achieving near maximal physiological (e.g., 95-95% of HR_{max}) and perceptual responses (e.g., RPE values > 8). Moreover, significant differences found comparing WODs (e.g., VO_2 , $\% \text{VO}_{2\text{max}}$ and EE higher in the “Cindy”, and “Fran” resulted in significantly higher percentage of time spent above RER 1). Although physiological responses of the analyzed WODs are well within the ACSM’s recommendations for enhancing aerobic fitness and promoting total body mass and fat weight loss (Garber et al., 2011), due to the high-intensity of the workouts analyzed, together with the lack of research in this topic, the safety has not been defined for such programs. Limitations of the present study included, among others, the lack of inflammatory markers measures, a more detailed information regarding the strength training prescription. Other limitation of the present study is the calculating EE only during workout. Previous studies (24) have shown that

oxygen uptake remains elevated several hours following short intense workouts, a key point to consider these workouts in some populations. In future studies, EE will be monitored time after WODs to explain effects after exercise.

The present study provides greater insight into the physiological (e.g., HR, VO_2) and perceptual (e.g., RPE) responses of two typical CrossFit® workouts or WODs (e.g., “Fran” and “Cindy”). Results suggest that individuals practicing CrossFit® on a regular basis (2–3 times a week) can work at a sufficient intensity to meet the ACSM’s recommendations for enhancing aerobic fitness and promoting total body mass and fat weight loss. However, when recommending this kind of activity, there are some issues that must be recognized. First, is the apparently random exercise regimes and lack of individualization for participants of these programs (Hak, Hodzovic, & Hickey, 2013), as WODs are usually performed at high intensity, with a high number of repetitions and using heavy weight movements (Glassman, 2007). This could lead to episodes of muscle inflammation, and thus, questions have arisen with regards to the safety of this activity. Additionally, due to the high volumes and the high prevalence of injuries (e.g., shoulder and low back) reported (Hak et al., 2013), caution must be taken when programming WODs. In order to avoid possible health problems caused by repetitive high-intensities and poor technique, it would be recommended to organize a more balanced programming of workouts, reducing the number of “dangerous” exercises, and also combine CrossFit® WODs with aerobic-based training. Future studies should consider investigating acute and mid-term physiological, immunological and perceptual effects of CrossFit® training, including different gender, age groups and training experience.

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