2022 · *Retos Nº 46 / Págs. 309-322*

Summary of the evidence on responses and adaptations derived from CrossFit training. A systematic review.

Resumen de la evidencia sobre respuestas y adaptaciones derivadas del entrenamiento de CrossFit. Una revisión sistemática

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Abstract. Objective: The present review aims to describe the state of the scientific evidence that exists about acute and chronic adaptations of CrossFit training. Method: This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement (PRISMA). Original research articles published until 7 June 2020, were searched using five databases. A total of 994 original publications were found. A total of 62 papers matched the inclusion criteria. Results: Short-term effects: CrossFit training results in higher physiological demands than other training modalities. Different work of the day analysed by the studies have shown specific performance demand profiles. Besides psychological and mechanical acute effects have been found after CrossFit sessions. So, the negative moods perception appears to reduce after a CrossFit training session. Long-term effects: maximum oxygen consumption improves after CrossFit programmes, in which experienced athletes seem to achieve a higher gain than recreational athletes. Important changes in body composition have been reported by several studies included in this review. From a psychological perspective, CrossFit practitioners obtain a higher adherence to training than occurs in other training methodologies. Prospects and projects: Specific requirements of every work of the day should be studied for the correct administration to participants. Accumulative fatigue indexes should be explored as an overtraining syndrome in CrossFit athletes because several authors have reported psychological variables related to training addiction. Conclusion: CrossFit-based training drives several physiological changes that could be influenced by the athlete's expertise. Moreover, this type of training requires a high physiological demand, which is perceived by athletes. Nevertheless, participants achieve adherence to CrossFit regardless of their objectives. In the case of high-performance athletes, addictive exercise behaviours have been identified.

Keywords: Acute responses; Chronic adaptation; Physiology; Psychology.

Resumen. Objetivo: El objetivo de esta revisión es describir el estado de la evidencia científica relacionada con las respuestas agudas y crónicas del entrenamiento tipo CrossFit. Método: Éste estudio siguió las directrices de la guía Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Sólo se incluyeron artículos originales publicados con anterioridad al 7 de junio de 2022, fueron consultadas cinco bases de datos. Se encontró un total de 994 publicaciones originales. De ellas, un total de 62 artículos cumplieron los criterios de inclusión. Resultados: los practicantes adquieren una mayor adherencia a la práctica de CrossFit y, al mismo tiempo, mejoran su rendimiento físico. El entrenamiento de CrossFit resulta en una mayor demanda fisiológica que otros deportes. Cada entrenamiento y prueba de competición requiere de un perfil de rendimiento específico. Los atletas desarrollan una buena composición corporal tras el entrenamiento de CrossFit a lo largo del tiempo. Proyectos y perspectivas: el requerimiento específico de cada entrenamiento y prueba deben ser estudiados para su categorización. Los índices de fatiga acumulada deberían ser explorados como detectores de síndrome de sobreentrenamiento en practicantes de CrossFit ya que los autores han reportado variables psicológicas relacionadas con la adicción. Conclusiones: El entrenamiento basado en el CrossFit impulsa varios cambios fisiológicos que podrían estar influenciados por la experiencia del atleta. Además, este tipo de entrenamiento requiere una alta demanda fisiológica que es percibida por los practicantes. Sin embargo, los participantes logran adherirse al CrossFit independientemente de sus objetivos. En el caso de los deportistas de alto rendimiento, se han identificado conductas adictivas a este tipo de ejercicio.

Palabras clave: Respuesta aguda; Adaptaciones crónicas; Fisiología; Psicología.

Introduction

CrossFit (CF) has been categorised by many authors as a high-intensity conditioning programme that uses successive movements with significant strength and speed demands along with resistance work (Weisenthal, Beck, Maloney, DeHaven, & Giordano, 2014). Functional movements are used in this type of training, structured by circuits in continuous variation. Different exercises of different modalities, such as weightlifting, gymnastics and cyclic exercises with a greater cardiovascular component such as running, swimming, and cycling, can be combined in CF (Martínez-Gómez et al., 2019). Similarly to interval training, CF offers short and unstructured rest periods, which allows participants the opportunity to raise the levels of demand induced by exercise.

Fecha recepción: 13-02-22. Fecha de aceptación: 22-06-22
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The practice of this training modality is becoming increasingly widespread among different types of practitioners with a view to achieving goals such as improving physical fitness, body image, recreation, and social relationships (Fisher, Sales, Carlson, & Steele, 2017). In order to achieve these goals, CF training provides chronic adaptations based on the acute effects of its sessions, which depend on the usual physical training variables, such as magnitude, duration, and frequency of stimulus (Powers & Jackson, 2008; Wasfy & Baggish, 2016). In this sense, several authors have shown that a high acute response to cardiovascular training and a significant increase in fitness levels (aerobic and anaerobic performance) can be achieved through CF training (Butcher et al., 2015; Paine, Uptgraft, & Wylie, 2010; Smith et al., 2013).

However, this type of training is sometimes excessive even for the most experienced participants (Weisenthal et al., 2014), making it difficult to understand acute and chronic responses to these activities (Fernández-Fernández, Sabido, Moya, Sarabia, & Moya-Ramon, 2015). In recent years, research specifically related to acute and chronic effects of CF training has been published in a variety of journals with diverse subject matter. The popularity of training within the fitness industry, however, is not proportional to the quantity and quality of studies regarding this modality (Box et al., 2019). The main study approaches towards this discipline have focused on injury incidence (Stracciolini, Quinn, Zwicker, Howell, & Sugimoto, 2020), performance determinants (Martínez-Gómez et al., 2019; Martínez-Gómez et al., 2019) and psychological effects derived from the practice (Dominski, Serafim, Siqueira, & Andrade, 2021). There are several literature reviews that address CF training in general, focusing on participant safety and subjective adaptations, but there exist no reviews focused on training responses and adaptations in this discipline. The aim of the present review is to describe the state of the scientific evidence that exists in relation to acute and chronic adaptations of CF training, in order to provide a context for future researches, as well as to inform coaches and athletes regarding the main effects studied under the CF methodology.

Methods

For the development of this review, we followed the criteria of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Urrútia & Bonfill, 2010), defining the bibliographic search strategy under the terms «CrossFit» and «Adaptation» in the databases used (PubMed, SportDiscus, Scopus, Embase, and Google Scholar). Potential studies were searched from the inception up to 2 July 2020. An update was performed on 7 June 2022.

The inclusion criteria included articles that focused on acute or chronic responses or adaptations following sessions of CF. Subsequently, the data were categorised, analysed and summarised. After the selection of the articles, a coding scheme was designed for content analysis to gather a variety of categories of information appropriate to address the study objectives. The scheme design followed the suggestions of Marshall and Rossman (2014), and Rivera and Upchurch (2008). Each article was coded according to author and year of publication, subject matter, sample (n), intervention type, experimental design, and findings. To ensure analysis and reliability in data extraction and subsequent presentation in the results, the process of article selection through the literature search and screening was conducted independently by two researchers. Every included article was assessed using the PEDro scale (Morton, 2009). This scale is composed of 11 items, and depending on compliance, each trial is given a total PEDro score, ranging from 0 to 10. It should be noted that not all the papers included in this review performed an intervention, and there were others in which this process was not performed and comparisons between the groups were made. These observational studies could provide evidence that allows a comprehensive overview of the issue.

Results

A total of 994 articles were identified in the different databases, of which 337 were eliminated due to duplication. Of the remaining 657, 539 were excluded from the process because they did not reveal a relationship with the subject matter after reading the titles and abstracts. After reading the full texts, 63 articles were discarded because they did not provide enough data or the studies did not focus on CrossFit adaptation, therefore they did not meet the inclusion criteria. A total of 55 articles were included in the review. All studies' details and quality are described in Table 1-3 (PEDro score, acute and chronic responses, respectively). Following the update review, a total of 62 articles were included in the review (Figure 1).

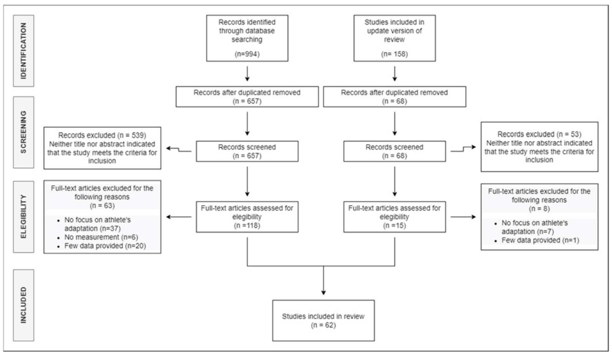

Figure 1. Selection of studies included in the review. PRISMA Flowchart.

Table 1.
PEDro Score

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Adami et al. (2022)	+	-	-	-	-	-	-	+	+	+	+	4
Andrade et al. (2018)	+	-	-	-	-	-	-	+	+	-	-	2
Ayar (2018)	+	-	-	-	-	-	-	+	+	+	+	4
Bahremand et al. (2020)	+	+	-	+	-	-	-	+	+	+	+	6
Barbieri et al. (2019)	+	-	-	-	-	-	-	+	+	+	+	4
Bellar et al. (2015)	+	-	-	-	-	-	-	+	+	+	+	4
Borras et al. (2017)	-	-	-	+	-	-	-	+	+	+	-	3
Box et al. (2019)	+	-	-	-	-	-	-	+	+	+	+	4
Box et al. (2018)	+	-	-	+	-	-	-	+	+	+	+	5
Butcher et al. (2015)	+	-	-	-	-	-	-	+	+	+	+	4
Butcher et al. (2015)	+	-	-	-	-	-	-	+	+	+	+	4
Bycura et al. (2017)	+	-	-	+	-	-	-	+	+	+	+	5
Carnes & Mahoney (2019)	+	+	-	+	-	-	-	+	+	+	+	6
Chacao et al. (2019)	+	-	-	-	-	-	-	+	-	-	+	2
Costa et al. (2021)	+	+	-	+	-	-	-	+	+	+	+	6
Coyne & Woodruff (2020)	+	-	-	-	-	-	-	+	-	-	+	2
Crawford et al. (2018)	+	-	-	-	-	-	-	+	+	+	+	4
Davies et al. (2016)	+	-	-	-	-	-	-	+	-	-	-	1
Dehghanzadeh et al. (2021)	+	+	-	+	-	-	-	+	+	+	+	6
Drake et al. (2017)	+	-	-	-	-	-	-	+	+	+	+	4
Drum et al. (2017)	-	-	-	-	-	-	-	+	-	+	+	2
Escobar et al. (2017)	+	-	-	-	-	-	-	+	-	-	+	2
Faelli et al. (2020)	+	-	-	-	-	-	-	+	+	+	+	4
Fealy et al. (2018)	+	-	-	-	-	-	-	+	+	-	+	3
Feito et al. (2019)	+	+	-	+	-	-	-	+	+	+	+	6
Feito et al. (2018)	+	-	-	-	-	-	-	+	+	+	+	4
Fernández Fernández et al. (2015)	+	-	-	-	-	-	-	+	+	+	+	4
Fisher et al. (2017)	+	-	-	-	-	-	-	+	-	+	+	3
Freire et al. (2020)	+	-	-	-	-	-	-	+	-	+	+	3
Heinrich et al. (2014)	+	+	-	+	-	-	-	+	+	+	+	6
Heinrich et al. (2021)	+	-	-	-	-	-	-	+	+	-	+	3
Kliszczewicz et al. (2015)	+	+	-	-	-	-	-	+	+	-	+	4
Lichtenstein & Jensen (2016)	-	-	-	-	-	-	-	+	-	+	+	2
Maia et al. (2019)	-	-	-	-	-	-	-	+	+	-	-	1
Mangine et al. (2020)	+	-	-	+	-	-	-	+	+	+	+	5
Mangine et al. (2018)	+	-	-	+	-	-	-	+	+	+	+	5
Marin et al. (2018)	-	-	-	-	-	-	-	+	-	+	+	2
Martínez-Gómez et al. (2019)	+	-	-	+	-	-	-	+	-	+	+	4
Martínez-Gómez et al. (2019)	+	-	-	-	-	-	-	+	-	+	+	3
Maté-Muñoz et al. (2018)	+	-	-	-	-	-	-	+	+	+	+	4
Murawska-Cialowicz et al. (2015)	-	-	-	-	-	-	-	+	+	+	+	3
Osipov et al. (2019)	+	+	-	+	-	-	-	+	+	+	+	6
Partridge et al. (2014)	+	-	-	-	-	-	-	+	-	+	+	3
Perciavalle et al. (2016)	+	-	-	-	-	-	-	+	-	+	+	3
Pereira et al. (2019)	+	+	-	+	-	-	-	+	+	+	+	6
Perna et al. (2018)	+	+	-	+	-	-	-	-	+	+	+	5
Pickett et al. (2016)	-	-	-	+	-	-	-	+	-	+	+	4
Poderoso et al. (2019)	+	-	-	-	-	-	-	+	+	-	+	3
Prado-Dantas et al. (2018)	+	-	-	-	-	-	-	+	+	-	+	3
Prado Dantas et al. (2018)	+	-	-	-	-	-	-	+	+	-	+	3
Sánchez-Alcaraz & Gómez-Mármol (2015)	+	-	-	-	-	-	-	+	-	+	+	3
Shaw et al. (2015)	+	-	-	-	-	-	-	+	+	-	+	3
Sibley & Bergman (2018)	-	-	-	-	-	-	-	+	-	+	+	3
Smith et al. (2013)	+	-	-	-	-	-	-	-	+	-	+	2
Tafuri et al. (2016)	+	-	-	-	-	-	-	+	-	+	+	3
Tibana et al. (2016)	-	-	-	-	-	-	-	+	+	-	+	3
Tibana et al. (2018)	+	-	-	-	-	-	-	+	-	+	+	3
Tibana et al. (2017)	-	-	-	-	-	-	-	+	-	+	+	3
Tibana et al.(2021)	+	-	-	-	-	-	-	+	+	+	+	4
Tibana et al. (2022)	+	-	-	-	-	-	-	+	+	+	+	4
Wilke et al. (2020)	+	-	-	-	-	-	-	+	-	-	+	2
Woolf & Lawrence (2017)	-	-	-	-	-	-	-	+	+	-	+	3

1. Eligibility criteria were specified; 2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received); 3. Allocation was concealed; 4. The groups were similar at baseline regarding the most important prognostic indicators; 5. There was blinding of all subjects; 6. There was blinding of all therapists who administered the therapy; 7. There was blinding of all assessors who measured at least one key outcome; 8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; 9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by «intention to treat»; 10. The results of between-group statistical comparisons are reported for at least one key outcome; 11. The study provides both point measures and measures of variability for at least one key outcome.

Acute Responses

Physiological responses

Firstly, one of the most studied variables from a physiological point of view is the acute response of the heart rate (HR) during CF-type training, with an observed sharp increase in this parameter. Studies such as those by Shaw et al. (2015), Fernández-Fernández et al. (2015), Maté-Muñoz et al. (2018) and Butcher et al. (2015) found HRs above 90% of maximum during the execution of CF-type training.

Another variable studied in the descriptive studies of the acute physiological effects of CF training is oxygen consumption (VO_2). The review indicated differences in the respiratory coefficient depending on the type of *work of the day* (WOD) that is proposed. For example, the work of Fernández-Fernández et al. (2015) found that a shorter and more intense WOD («Fran») led to a significantly longer work time with a coefficient above one (76% of the duration of the WOD) indicating a significant prevalence of anaerobic pathways. In contrast, a WOD like Cindy would have an aerobic predominance since participants achieve a respiratory coefficient higher than one the 47% of the effort's length. These results are similar to those of Escobar et al. (2017), who found values around that coefficient of one in WODs of intermediate volume with respect to the previous ones such as the «Rahoi» WOD.

Another variable that we found in a few studies that assessed acute response to CF sessions was the blood lactate concentration. Several studies have documented significant increases in this variable after CF training (Escobar et al., 2017; Shaw et al., 2015; Tibana et al., 2016). This considerable increase has been correlated in some studies with an increase in HR depicting a close relationship between both variables in CF training (Maté-Muñoz et al., 2018).

Although studies focused on hormonal changes are scarce in this discipline, an increase in oxidative stress markers has been reported after CF-type training similar to a task of running to exhaustion at an intensity of 90% of maximum HR for 20 minutes (Kliszczewicz et al., 2015 In addition, the acute effect of a CF WOD leads to an increase in inflammatory response that is reduced in the following days (Faelli, et al., 2020; Tibana, et al., 2016). Another remarkable result from the same research group was the increase in brain-derived neurotrophic factor (BDNF), which occurred only in the high-intensity group (Tibana, et al., 2022).

Other physiological variables such as body temperature, blood pressure (BP), glucose, or heart rate variability (HRV) have also been studied acutely after CF sessions, with increases observed in all of these variables, except for HRV in men (Maia, et al., 2019; Prado-Dantas, De Souza, De Matos, et al., 2018; Shaw et al., 2015).

Table 2.
Acute response

Study	Theme	Subjects	Intervention or analysis	Experimental design	Finding
Butcher et al. (2015)	Physiological and Subjective responses	57 (19 men and 38 women)	Cross-sectional and observational study	Two types of CrossFit workouts. Continuous functional work and intervallic functional work. Monitoring HR and RPE	The mean HR was significantly higher in continuous training than in intervallic training despite reporting a similar RPE. Experienced athletes obtained higher HR values than novices
Butcher et al. (2015)	Physiological responses	14 (10 men and 4 women)	Descriptive study	Take the marks of the main WODs (Fran, Cindy, Grace and CrossFit Total) and incremental physiological test. Subsequently follow up the athletes during the OPEN WODs.	Performance of benchmark CrossFit WODs cannot be predicted by VO2 Max, Wingate power/capacity, nor can it be predicted by respiratory compensation or anaerobic thresholds. The sole determinant of the study was strength
Drake et al. (2017)	Physiological and motor responses	6 men	Experimental intervention	Initial evaluation and after four weeks of CF type training is re-evaluated. Anthropometry, cardiovascular function, physical condition, biomechanical measurements, nutritional and psychological status	CF in the short term will improve below-average components of fitness and maintain the above-average components. On the other hand, it will induce states of functional overexertion (higher overall performance, but worse mood and inflammatory state)
Drum et al. (2017)	Subjective responses	203 people	Descriptive study	Subjects answered the inquiry form at their own convenience via a website (Qualtrics) containing the questionnaire, which consisted of 19 questions. Surveys were completed anonymously	CrossFit® leads to «very hard» perceived exertion causing detrimental post-exercise effects on muscle and ventilatory function in experienced athletes. Improved training progression with adequate recovery schedules are needed to prevent severe muscle injury, such as exertional rhabdomyolysis.
Escobar et al. (2017)	Physiological responses	18 (7 men and 11 women)	Descriptive of a WOD	Analysis of the same WOD on two occasions (separated by three days)	No significant differences were observed in the variables measured at both time points. During both, high levels of lactate, significant increase of VO2 and RER
Fernández Fernández et al. (2015)	Physiological and subjective responses	10 men Healthy adults	Descriptive of two WODs	A laboratory test, and two WODs, separated by one week	90-95% of HRmax; LA values >10 mmol-1; RPE values >8. RER higher in «Fran» than in «Cindy».
Fisher et al. (2017)	Subjective responses	314 (132 men and 182 women)	Pilot study (quantitative approach using questionnaires)	A questionnaire in line with the Exercise Motivations Inventory-2 (EMI-2). Self-report questionnaire capable of measuring exercise motives in adult men and women (stress management, revitalization, enjoyment, challenge, social recognition, affiliation, competence, health…	CrossFit participants were more likely to report higher levels of intrinsic motivation, such as enjoyment, challenge, and affiliation, whereas personal training clients reported higher values for health-related reasons.
Kliszczewicz et al. (2015)	Physiological responses	10 men Healthy adults	Descriptive of a WOD	Blood samples taken before and after (randomized, crossover design) 20 minutes CF workout	Increase in Lipid Peroxidase (LP) and decrease in Protein Carboxylase (PC). Antioxidant capacity decreases in the post, but recovers with the passing of the hours
Maia et al. (2019)	Physiological and motor responses	3 (1 man and 2 women)	Descriptive cross-sectional	Monitoring of variables during three days of competition	Decrease in CMJ and HRV post-competition
Marin et al. (2018)	Subjective responses	493 (351 men and 148 women)	Cross-sectional descriptive and correlational study	Classified into two groups: RT and CF. Complete an online questionnaire	Intrinsic motivation CF members. RT participants external regulation
Maté-Muñoz et al. (2018)	Physiological, motor and Subjective responses	32 men	Descriptive study	Analysis of three types of WODs. 1) Gymnastics, 2) Metabolic and 3) Weightlifting.	Vigorous intensity in the three WODs. Higher HR in the «Cindy» (gymnastics) and jumping rope than in weightlifting. Muscle fatigue occurred in response to «Cindy» and Power Clean, but not in response to the in rope skipping
Perciavalle et al. (2016)	Physiological and cognitive responses	15 men	Cross-sectional study	Three types of WODs (strength and power, gymnastic and metabolic). Performed twice 24 hours apart	Significative increases in blood lactate. Increases in blood glucose. Increase in IL-6 and IL-10 but not after all WODs. Significant worsening reaction time. At 48 h tend to return to baseline
Pereira et al. (2019)	Subjective responses	20 men	Experimental intervention	10 subjects experienced in CF and 10 inexperienced subjects performed a single session of CF. Mood states (BRUMS scale)	A single CF training session is powerful enough to induce changes in the moods of both trained and untrained individuals.
Prado Dantas et al. (2018)	Physiological and motor responses	10 men	Descriptive cross-sectional study	A single WOD and measures pre-post	Lower CMJ, decreased upper limb power and increased body temperature in extremities
Prado-Dantas et al. (2018)	Physiological responses	10 men	Descriptive study	A CrossFit session and a bodybuilding training session	Hypotensive effect of CrossFit with just one training session
Shaw et al. (2015)	Physiological responses	20 men Sedentary	Experimental intervention	A laboratory test, and a single bout of CrossFit	Increase in HR, RPP and lactate
Tibana et al. (2016)	Physiological responses	9 men	Cross-sectional study	Three types of WODs (strength and power, gymnastic and metabolic). Performed twice 24 hours apart	Increases blood lactate and blood glucose. Increase in IL-6 and IL-10 but not after all WODs. At 48 h tend to return to baseline
Wilke et al. (2020)	Subjective responses	79 (36 men and 43 women)	Descriptive study	The athletes responded to a battery of three questionnaires (Fear of Competition Index, Athletic Coping Skills Inventory, Mindfulness Awareness Scale)	Competition anxiety is a frequent finding in CF athletes. Although factors such as age and performance level do not appear to have a significant impact on the nature and magnitude of reported fears, women may be more vulnerable than men.

Table 3.
Chronic responses

Study	Theme	Subjects	Intervention or analysis	Experimental design	Finding
Andrade et al. (2018)	Motor responses	16 (8 men and 8 women)	Descriptive observational study	To assess the flexibility of the lower limbs, each individual was subjected to a maximum passive amplitude of 3 movements at the hip, knee and ankle joints. The one repetition maximum (1 RM) test was used to assess strength.	It was observed that 18.75% of the total sample had a small flexibility rating. The research verified and identified that; good flexibility influences maximal strength performance in CrossFit practitioners.
Ayar (2018)	Subjective responses	200 (161 men and 39 women)	Descriptive correlational study	A questionnaire was used as the main method of data collection. The REMS and the Recreational Exercise Motivation Scale (REMM) which comprehensively assesses factors that motivate individuals to engage in recreational physical activity,	A difference was found in the rivalry subdimension of the REMM scale according to the gender variable in the participants attending the CF centres ($p<0.05$). Male individuals participate more in CF because of competition than the female gender.
Barbieri et al. (2019)	Structural and Physiological response	16 (8 men and 8 women)	Experimental and cross-sectional	Familiarization and evaluate body composition and 72 h after maximum incremental test on cycloergometer. One group CF and the other endurance	The CF group presented greater muscle mass but worse ventilatory threshold, first ventilatory threshold power and second ventilatory threshold power than the RT group. In addition, heart rate recovery (HRR) was significantly lower for the CF group.
Bellar et al. (2015)	Physiological responses	32 healthy adult males	Descriptive study	Subject sorted in two group regarding to experience. All of them carried out two CrossFit performance testing sessions (AMRAP and 21-15-9 rep) after a short dynamic warm up and underwent testing to determine maximum aerobic capacity (VO2max) and anaerobic power (Wingate) within the course of a three-week period.	The AMRAP workout performance was also associated with both aerobic fitness and anaerobic power. In addition, AMRAP is suggested useful for novice whilst the rep scheme related to CrossFit experience.
Borras et al. (2017)	Physiological responses	82 (42 men and 40 women) Teenagers	Experimental intervention	Two months of CrossFit training included in P.E. classes. Test Course-Navette for evaluate	Significant improvement in the Course-Navette test (improvement of aerobic capacity)
Box et al. (2018)	Subjective responses	12 (5 male and 7 female) adults with more than 6-months of CFT experience	Experimental intervention	Subjects wore a HR monitor during WOD (from Open 16.1 to 16.5, one per week) and completed a mood's survey (POMS) over 5-week period. It was allowed unlimited attempts within week to achieve the best possible score.	Baseline mood (in a controlled setting) and pre-workout mood did not differ across the 5-weeks of the competition, nor did the five bouts chronically alter mood. Negative moods, as Fatigue, increased immediately following the workout, while feelings of Vigour remained elevated throughout the entire session
Box et al. (2019)	Subjective responses	737 adults (CF experience)	Cross-sectional study	An online questionnaire was used to reach a broad sample of individuals. The survey, was distributed to CF gyms around the world.	Those who had been in the relationship longer reported more motives associated with the relationship. In addition, the motivational variables varied whether or not individuals had competed or not
Bycura et al. (2017)	Subjective responses	737	Descriptive correlational study	The Exercise Motivation questionnaire was distributed. Inventory (EMI-2) and supplied to CrossFit Box and affiliated members	Significant correlation between the duration and frequency of CF practice and the items of the questionnaire related to motivation.
Carnes & Mahoney (2019)	Physiological responses	21 men	Experimental study	Laboratory test before and after 12 weeks of CF or polarized endurance training	Both groups increased VO2max, but with larger magnitude in polarized than CF
Chacao et al. (2019)	Structural	19 men	Descriptive study	Anthropometric measurements and, consequently, the measurement of body composition and somatotype in CrossFit athletes were carried out.	Low body fat values and high lean mass development. The results have favourable characteristics that relate CrossFit practitioners to high performance athletes.
Coyne & Woodruff (2020)	Subjective responses	149 women	Descriptive correlational study	Five affiliated CF centres were given questionnaires to be filled in by the clients (MBSRQ-BASS, BIQ, RSES, EAT-26). These questionnaires take into account body image, mood and possible eating disorders.	CF skill was strongly related to body image. Duration in CF was negatively associated with the existence of some type of eating disorder. And no CF variable was associated with self-esteem.
Crawford et al. (2018)	Physiological responses	25 men Healthy Adults	Experimental intervention	A nine-week period to determine the association of HIFT-induced changes in physiologic measures of fitness and changes in physical work capacity	Physiologic measures of fitness (e.g., aerobic capacity) were significantly associated with physical work capacity and this relationship was even stronger at HIFT post-intervention
Davies et al. (2016)	Subjective responses	206 (87 men and 119 women)	Correlational study	The regulation of CrossFit behaviour was measured with the BREQ-2 Questionnaire; which is a 19-item self-report measure (Self-Determination Theory). On the other hand, autonomy, competence and relationships in CrossFit were measured with the Basic Psychological Needs in Exercise Scale (BPNE).	Participants who attended CrossFit more frequently had significantly higher levels of BPN satisfaction. This study provided empirical support for previous theoretical connections between NPB satisfaction and self-determined regulation towards exercise.
Fealy et al. (2018)	Physiological responses	13 (5 men and 8 women) with obesity	Experimental intervention	Six weeks of CrossFit training (three times per week) and blood samples	Significantly reduces fat, diastolic blood pressure and blood lipids. Increased gas oxidation and molecular adiponectin; which correlates with increased insulin sensitivity. Benefit for type II diabetics
Feito et al. (2018)	Motor responses	29 (15 men and 14 women)	Cross-sectional descriptive and correlational study	Participants were required to complete four consecutive studies. Wingate anaerobic testing, and a 15-minute CrossFit style workout.	Ability to predict performance in CrossFit type training from the second and third Wingate.
Feito et al. (2019)	Physiological and structural responses	18 (8men and 10 women) Overweight adults	Experimental intervention	Eight weeks of aerobic and resistance training (A-RT) compared to HIFT. Glucose and body composition and anthropometry.	No significant differences were found for body composition or glucose variables within-or between-groups
Freire et al. (2020)	Subjective responses	60 (22 men and 38 women)	Cross-sectional and descriptive study	The study was developed following the guidelines for observational studies (STROBE). A semi-structured questionnaire developed from others was administered. It was based on the following: «Eating attitudes Test-26» (EAT-26), «Questionnaire for the diagnosis of Orthorexia» (ORTO-15), «Body Shape questionnaire» (BSQ) and «Scale of dedication to exercise» (SDE).	Association between body dissatisfaction, exercise addiction and risk behaviour for eating disorders. In addition, individuals dissatisfied with their body showed a higher level of exercise addiction and risk behaviour for eating disorders. Women showed a greater presence of mental disorders than men, and fitness participants reported a greater presence of exercise addiction than CF practitioners.

Heinrich et al. (2014)	Subjective responses	23 (10 men and 13 women)	Intervention	Two groups (traditional resistance and strength training, and HIFT training group). They trained for two months and psychological variables were measured pre and post training.	HIFT participants spent less time exercising per week, but were able to maintain exercise and were more likely to intend to continue. High-intensity exercise options should be made available to the public in the HIFT study. health interventions
Heinrich et al. (2021)	Motor and Subjective responses	7 (2 men and 5 women) Elders	Experimental intervention	Two months of CrossFit training (two sessions per week)	High adherence. Significant improvement in 1 of 5 physical functions measures. CrossFit seemed feasible and showed promise. to counteract the loss of physical function and sedentary lifestyles, behaviours associated with aging
Lichtenstein & Jensen (2016)	Subjective responses	603 (328 men and 270 women)	Descriptive study	The Exercise Addiction Inventory (EAI) was used to measure exercise addiction. The amount of exercise was reported weekly in the categories: 0-2, 2-4, 4-6, 6-8, 8-10, 10+ h/week	The group reporting elevated EAI scores were represented by young men and men with high amounts of weekly exercise. In addition, we found that more CF addicts reported a greater number of negative beliefs and attitudes about exercise
Mangine et al. (2018)	Physiological and structural responses	23 (12 men and 11 women)	Cross-sectional study	Anthropometric, biochemical and physiological measurements of two groups (experienced and amateurs).	A better body composition and cardiorespiratory parameters were found in experienced athletes compared to amateurs, but no differences were found at the hormonal level.
Mangine et al. (2020)	Physiological and structural responses	23 (12 men and 11 women)	Cross-sectional study	Anthropometric, biochemical and physiological measurements of two groups (experienced and amateurs).	A better body composition and cardiorespiratory parameters were found in experienced athletes compared to amateurs, but no differences were found at the hormonal level.
Martínez-Gómez et al. (2019)	Motor responses	20 men	Descriptive cross-sectional	Incremental load test for the evaluation of 1RM, average power and peak power. Performance in five different workouts (WODs) was measured on different days. Athletes were assigned to a high or low performance group based on the mean score.	Strength and power levels measured in a maximal squat test are strongly related to performance in WODs.
Martínez-Gómez et al. (2019)	Motor responses	20 men	Descriptive cross-sectional study	Incremental load test for the evaluation of 1RM, average power and peak power. Performance in five different WODs was measured on different days. Athletes were assigned to a high or low performance group	Strength and power levels measured in a maximal squat test are strongly related to performance in WODs.
Murawska-Cialowicz et al. (2015)	Physiological and structural responses	12 (7 men and 5 women) Healthy, physically fit adults	Experimental intervention	Blood samples, physiological and anthropometric measures taken before and after three months of training	Increase in BDNF and no change in irisin (only decreases in women). Improves aerobic capacity, VO2 Max. and adipose tissue
Osipov et al. (2019)	Physiological responses	33 men (young people 16-17 years old)	Longitudinal study	Two groups of young judo fighters divided into two groups (CrossFit group and Judo group) trained for 10 months and held competitions in their discipline.	Significant superiority among those who used CrossFit training in the coefficient of active combat time in competitive events. Among athletes in the CrossFit group, lactate data was significantly higher. The percentage of duels won by athletes who trained CrossFit was higher.
Partridge et al. (2014)	Subjective responses	144 (56 men and 88 women)	Descriptive study	Three questionnaires were administered to CF athletes. First questionnaire was to obtain demographic characteristics. Second questionnaire was the Achievement Goals for Sport Questionnaire (AGQ-S). And Perceived Motivational Climate in Sport Questionnaire (PMCSQ).	Men reported higher levels of performance approach goals and females reported higher levels of mastery avoidance. Participants who reported shorter membership times had significantly higher mastery goals
Perna et al. (2018)	Physiological, motor and structural responses	23 (14 men and 9 women)	Experimental intervention	Two groups assigned to one type of training (CrossFit or swimming). Two months (60 min, three times per week). Measures pre and post intervention	CrossFit is more effective than swimming for total fat mass loss (both gynoid and android)
Pickett et al. (2016)	Subjective responses	276 (117 men and 157 women)	Descriptive correlational study	Various scales were used and modified to obtain the information required by the study objective. Some of these were the multidimensional scale developed by Warner and a version of the SERV-PERVAL scale.	Explicit commitment to community-building was positively associated with a higher evaluation of the fitness product and the perception of individual progress. A high feeling of community is perceived by CF users.
Poderoso et al. (2019)	Physiological responses	29 (17 men and 12 women)	Descriptive cross-sectional	A week of CF training and blood samples before and after nine month of CF intervention	Testosterone values were significantly higher. Cortisol levels were lower at all times compared to the initial level before training. Significant effects on CD8 levels at different times and between genders, and no differences in CD4 levels were observed
Sánchez-Alcaraz & Gómez-Mármol (2015)	Subjective responses	104 (62 males and 42 females) (aged 12-16 years) Students	Experimental intervention	Intervention in the Didactic Unit with eight CF type sessions. Previously and each time they did a session, a questionnaire was administered to them	Perception of effort level quite high. Level of fun and learning with average values. Boys show significantly higher values in this variable than girls. Finally, older boys reflect a higher effort, but less fun.
Sibley & Bergman (2018)	Subjective responses	322 (210 men and 112 women)	Descriptive correlational study	Participants completed a demographic questionnaire. They then completed the GCEQ, the BNSW and the BREQ (goals, satisfaction of basic psychological needs, behavioural regulation …).	Frequency of participation was positively predicted by intrinsic regulation. Intrinsic goal content and satisfaction of the need for competition was negatively predicted by external regulation.
Smith et al. (2013)	Physiological and structural responses	43 (23 men and 20 women) Healthy adults	Experimental intervention	Anthropometric measures and laboratory test pre-post 10 weeks of CF training	Increase in VO2 Max. and decrease in body fat percentage
Tafuri et al. (2016)	Structural responses	90 (26 men and 64 women)	Observational study	Three groups (CrossFitters, weightlifters and bodybuilders), to which the FMS evaluation tests are carried out.	CrossFitters seem to have a high level of agreement in the scores obtained. CrossFit seems to produce a marked symmetry in some of the fundamental movements compared with weightlifters and bodybuilders
Tibana et al. (2018)	Motor responses	22 men	Correlational study	Establish a relationship between the maximal weights of the movements moved in squat and deadlift and the performance in CF WODs	Superior strength in basic exercises, such as the squat, can contribute to Olympic movements.

Tibana et al. (2017)	Physiological and structural responses	15 men	Correlational study	Two groups of CrossFitters (best and worst performers). Body composition assessment, maximal strength tests, cardiovascular fitness and the WOD15.5 were performed on separate days.	Subjects with lower body fat, higher muscle strength and VO2 Max perform better on the WOD15.5
Woolf & Lawrence (2017)	Subjective responses	34 Open participants	Descriptive study	A questionnaire with both qualitative and quantitative questions was administered to the athletes before and after the Open	Strong social and sporting identity of the users in which no significant differences were observed after the Open events

Motor responses

From the perspective of the influence on mechanical variables, only two studies have been identified that have assessed acute responses through the jump test and reaction response after CF sessions. A study by Prado Dantas et al. (2018), showed how CF training decreased jumping ability as measured by a countermovement jump (CMJ) test. These authors found that after training, jumping performance decreased. Similar results were shown in the study by Maté-Muñoz et al. (2018), in which they found that this decrease was observed to be more typical of WODs linked to weightlifting or gymnastic skills, and not to training with the use of a skipping rope.

The measurement of reaction time has also been a tool to measure acute impact during CF training. A study by Perciavalle et al. (2016) showed a decrease in reaction test performance reflected in time (+11%) and an increase in the number of errors (+16%) suggesting a neural fatigue linked to this detriment of attentional aspects after CF training.

Subjective responses

In this section, we introduced the variables that reflect the perception of the effort or mood of the participants after acute sessions of CF. The most studied variable under this approach is the rating of perceived exertion (RPE), which is used to monitor exercise intensity (Foster et al., 2001). In particular, in studies assessing RPE, evidence showed that participants reported that training was «very hard» or «very, very hard» regardless of the measurement scale and type of WOD (Butcher et al., 2015; Fernández-Fernández et al., 2015; Maté-Muñoz et al., 2018; Sánchez-Alcaraz & Gómez-Mármol, 2015).

The participants' moods and emotions have also been studied in the literature. Pereira et al. (2019) found that, after a CF session, the scores for emotions such as will, confusion, depression, and edginess, decreased immediately after the session. Another variable in which CF practitioners tend to score high is that related to the practitioners' perceptions of enjoyment and fun (Sánchez-Alcaraz Martínez & Gómez-Mármol, 2015), even when compared to other modalities such as conventional strength training on their own or with a personal trainer (Box et al., 2018; Fisher et al., 2017; Marin et al., 2018). However, it is also worth noting that studies that acutely assessed negative emotions such as feelings of anxiety also found high values in CF athletes (Wilke, Pfarr, & Möller, 2020).

Chronic Responses

Physiological responses

One of the main variables used for the classification of the performance level of athletes is maximum oxygen consumption (VO_{2max}). Several studies (Borras, Herrera, & Ponseti, 2017; Murawska-Cialowicz, Wojna, & Zuwala-Jagiello, 2015; Smith et al., 2013) have reported changes in VO_{2max} after CF-type interventions ranging from four to 12 weeks, observing changes in oxygen consumption of between 9% and 16%, with longer-duration interventions having the greatest impact on the change in this variable. These adaptations appear to be mediated by the experiences of the participants (Mangine et al., 2020) with the most experienced participants having higher values in this variable than recreational participants (+13%). Nevertheless, it has been shown that running polarize training achieves greater benefit than CF in runners athletes (Carnes & Mahoney, 2019). Therefore, VO_2 adaptation from CF could be not specific for running. However, a later study found no difference in peak VO2max between endurance athletes and CF athletes (Adami, et al., 2022). Therefore, VO2 adaptation from CF may not be specific for running.

Another studied physiological variable was the chronic adaptation of BP, analysed by two scientific studies. Drake et al. (2017) found, after four weeks of intervention, no differences in systolic blood pressure (SBP) in the users of a university recreation centre after implementing a CF programme. However, Fealy et al. (2018) found, in obese adults, a significant decrease in BP after the implementation of a six-week-long CF training programme.

Other recurring variables in medium- to long-term studies were the hormonal and protein changes that occur in the body. Positive modifications for health, such as the hormonal increase of adiponectin, irisin or testosterone, the decrease of cortisol, and improvement of insulin sensitivity after participating in CF-type training have been observed (Fealy et al., 2018; Mangine, Cebulla, & Feito, 2018; Poderoso et al., 2019). In this context, an increase in brain-derived neurotrophic factor (BDNF) levels was also confirmed as result of the study of Murawska-Cialowicz et al. (2015) after three months of CF-type training, reflecting the advantages of neurogenesis that this type of training could have. Another long-term adaptation is the increase in lactate, compared to other modalities with high anabolic profile.Noteworthy is the study by Osipov et al. (2019), which reported higher values of this variable in CF athletes after training, compared to judo training, over a period of 10 months of intervention.

Structural

One of the main structural chronic adaptations is linked to the gain of muscle mass and fat mass loss. Evidence in the literature has shown that CF practitioners increase fat-free mass (+1.33% kg), although this increase was slightly lower for male practitioners (+2% kg), and in muscle cross sections, mainly in the pectoral, arm, and thigh musculatures (Murawska-Cialowicz et al., 2015). This improvement seems to require more than four weeks of training, as changes in body fat levels are not produced with shorter training periods (Drake et al., 2017).

Another widely studied morphological variable in the chronic adaptations of CF training is fat mass. Considerable decreases in adipose tissue after CF training have been reported in several works, with changes ranging from an average of 7–18 % (Dehghanzadeh Suraki, Mohsenzade, Tibana, & Ahmadizad, 2021; Fealy, et al., 2018; Murawska-Cialowicz, et al., 2015; Smith, et al., 2013). These results are not shared by the studies of Feito et al. (2019) and Drake et al. (2017), who did not observe such decreases after the implementation of a CF programme; however, it should be mentioned that the number of participants in this study was very small (n = 6). In contrast, Perna et al. (2018) showed that CF training is able to reduce more fat mass markers than swimming training.

Another way to study the possible chronic adaptations of CF training is to compare practitioners of this modality with other types of populations. Studies such as the one by Barbieri et al. (2019) showed that CF athletes had higher values of fat-free mass than recreationally trained athletes (59.80 kg vs 49.60 kg, respectively). In addition, Mangine et al. (2020) found that CF athletes with more experience showed a lower percentage of body fat in the lower limbs than CF athletes with less experience (8.30% vs 6.70%, respectively). In line with these affirmations, the study by Chacao et al. (2019) confirmed that the characteristic morphotype of CF athletes would be meso-endomorphic.

Subjective

Psychological variables such as adherence to training have also been reflected in the literature among chronic adaptations, showing that a modality such as CF facilitates adherence to training. Heinrich et al. (2014), after comparing adherence to a CF programme to conventional strength and aerobic work, showed that a CF programmes could significantly improve adherence by using less time during their sessions than the second training programme, which is interesting regarding the initiation into fitness programmes. In a latter study, the same authors demonstrated how these effects were also observed in the elderly population, obtaining adherence values of 88% among the participants in a CF programme (Heinrich, Crawford, Langford, Kehler, & Andrews, 2021). This adherence to CF programmes is closely related to aspects such as fun or enjoyment that have been assessed in several studies (Box et al., 2018; Fisher et al., 2017; Marin et al., 2018; Pickett et al., 2016; Sánchez-Alcaraz & Gómez-Mármol, 2015; Woolf & Lawrence, 2017).

With regard to the achievement of adherence, the satisfaction of participants basic psychological needs (BPN) and motivation for training plays a fundamental role, and under this perspective there are several studies that have assessed this topic in CF practitioners. Several authors (Ayar, 2018; Partridge, Knapp, & Massengale, 2014; Sibley & Bergman, 2018) indicate a significant effect towards the practice of CF for competitive reasons in men compared to women. Davies et al. (2016) explored the relationships between BPN satisfaction (autonomy, relatedness, and competence), behavioural satisfaction toward CF, and actual participatory behaviours within the framework of the self-determination theory, and appreciated that participants who attended CF more frequently had significantly higher levels of BPN satisfaction in all three needs related to motivation type (38.80% of variance in autonomous regulation, 5.70% of variance in controlled regulation toward CF). In addition, Fisher et al. (2017) found that intrinsic motivation (i.e., affiliation, challenge, fun) and external regulation motivation (i.e., health concern, body weight control) in CF practitioners was higher than in other strength training modalities. Competence perception and intrinsic motivation were related to enjoyment and weekly exercise volume, when participants reached more than 300 minutes of accumulation during the practice week (Marin et al., 2018).

The studies that have aimed to assess the contributions of CF to the behaviour of its practitioners have also shown negative consequences of the practice of CF in the medium and long term. One of these variables is the addiction to this sport derived from its practice. Lichtenstein and Jensen (2016) found that 5% of the subjects involved in the study showed an addiction to exercise, and that young people were at highest risk for addiction. In the comparison of CF practitioners with fitness centre users, it was observed that young (aged <25 years) female fitness practitioners had greater tendencies to show exercise addiction than older CF practitioners (Freire et al., 2020). Body image and eating habits, however, present conflicting results in the literature. Coyne and Woodruff (2020) studied this variable among women who practiced CF and observed a positive trend in terms of satisfaction with body image and the time spent practising of this discipline, in addition to a negative trend for eating disorders. In addition, Freire et al. (2020)

observed that women showed significant differences in body dissatisfaction compared to men (84.00% vs 64.36%, respectively) and this correlated with the development of eating disorders, with a lower correlation in CF practitioners than in another sports like fitness.

Range of motion

Range of motion has been understood to be one of the variables that is fundamental for the optimisation of performance. Tafuri et al. (2016) found that the scores on the Functional Movement Screen (FMS) test for shoulder mobility were higher in CF practitioners than among weightlifters and bodybuilders. As regards the lower limbs, Andrade et al. (2018) observed that lower-limb passive amplitude and range of motion seem to influence maximal strength performance.

Predictors of performance by WOD type

In this last section, we will review the relationships of different variables with performance in different CF WODs to describe the influence these variables may have after chronic adaptations of this modality. Butcher et al. (2015) documented that performance in «Grace» and «Fran» (both measured in time to perform the WOD) seemed to be more related to force production capacity (r = -0.88 and -0.65, respectively) and anaerobic threshold (r = -0.61 and -0.53, respectively) than to oxygen consumption. However, in the «Cindy» WOD, there was no significance, association or prediction by any measured variable (Butcher et al., 2015).

Time-based training, such «as many repetition as possible» (AMRAP), appears to be mediated by VO2max and anaerobic power; whereas in a «21, 15, 9» training (repetition-based), it appears that the subject's experience is the sole predictor of performance (Bellar, Hatchett, Judge, Breaux, & Marcus, 2015).

For the WOD15.5, a positive correlation was observed between body fat percentage and WOD time (r=0.60), as well as negative correlations between time and muscle strength (snatch, clean and squat) and VO_{2max} (Tibana et al., 2016).

The relationship between performance in four consecutive Wingate tests and a WOD has been identified such that as the performance during an AMRAP-type WOD increases, so does the subject's ability to maintain VO_2, HR and respiratory exchange ratio (RER) values in successive Wingate tests (Feito et al., 2018).

Martínez-Gómez, et al. (2019), demonstrated the relationship between deep squat one-rep maximum (1RM) and performance in five WODs (Open «17.1», «17.2», «17.3», «17.4», and «17.5»). Moderate to strong trends (r=0.47-0.69) were shown between squat variables and performance in the first four WODs. In addition, these authors found that overall performance in five WODs (Open «19.1», «19.2», «19.3», «19.4», and «19.5») was related to jumping ability, and average and maximal power during the Wingate, relative maximal strength for the squat and bench press, and VO_{2max} and speed during the incremental test (r = 0.58 - 0.75). Measures of lower body muscular power and VO_{2max} jointly explained most of the variance (R^2 = 81%) in the overall performance of the WODs (Martínez-Gómez et al., 2019). Other authors supported this evidence in several WODs (Tibana et al., 2018; Tibana et al., 2017).

Discussion

Physiological adaptations

The responses that occur at the physiological level in the human body following a CF session have different characteristics and the authors of most studies that have evaluated these responses agree. As a high-intensity training programme, a significant increase in HR, increased VO_2, higher RER, and a significant increase in lactate levels occur (Butcher et al., 2015; Fernández Fernández et al., 2015; Perciavalle et al., 2016; Shaw et al., 2015). The high-intensity nature of CF training could be supported by a variety of studies that have found acute responses in variables such as increased rate pressure product, increased body temperature in the extremities, hypotensive effects after a session, increased blood glucose levels, decreased HRV, increased oxidative stress and increased pro /anti-inflammatory cytokines (Maia et al., 2019; Perciavalle et al., 2016; Prado-Dantas et al., 2018). All these acute responses are typical of an intense training stimulus such as CF WODs.

In addition, chronic modifications in variables such as aerobic capacity, VO_{2max} and BP have also been observed during CF training. Aerobic capacity is notably improved with CF training in novice or recreational users (Borras et al., 2017; Crawford, Drake, Carper, DeBlauw, & Heinrich, 2018; Murawska-Cialowicz et al., 2015) and young athletes (Smith et al., 2013). In addition, higher values have been observed in more experienced athletes, who had a greater capacity to produce energy aerobically, and who were more prepared to maintain efforts with higher absolute workloads (Mangine et al., 2020). This contrast in capacities between experienced athletes and beginners are observed in other sports too (Abdullah et al., 2017; Toskovic, Blessing, & Williford, 2002). Therefore, adaptations could be due to practicing at those intensities over time.

At the hormonal level, an increase in factors associated with anabolic processes, neurogenesis, and mobilisation of adipose tissue occur. Studies report an increase in testosterone levels, as well as a decrease in cortisol, resulting in an improvement of the testosterone-cortisol ratio (Fealy et al., 2018; Mangine et al., 2020; Murawska-Cialowicz et al., 2015). In this sense, this review could take a stand against previous research (Kraemer & Ratamess, 2005) that showed inconsistent evidence about hormonal changes after resistance training. Nevertheless, these results could be due to the concurrence training in CF, and in contrast to workouts in which only aerobic stimuli prevail (De Luccia, 2016).

Mechanical and structural adaptations

In some of the studies presented in this review, the acute effect of a CF session on force production is evaluated with vertical jump tests. Jumping capacity is reduced after CF-type training (Prado-Dantas et al., 2018), especially in those sessions in which force demand is high (Maté-Muñoz et al., 2018). This decrease may be due to neuromuscular fatigue processes and would be in line with other works in which a significant decrease in jumping capacity has been observed after performing high- intensity training (Jiménez-Reyes et al., 2018). Moreover, consistent results have been reported regarding the reduction of attentional processes after CF training (assessed through the reaction response test) whose reduction has been linked to fatigue of the nervous system (Perciavalle et al., 2016). These results concur with those of other studies in which, the reaction time increased after performing high-intensity training (Cherif et al., 2018).

From a morphological point of view, chronic adaptations in CF seem to be characterised by an increase in cross-section area and fat-free mass (Drake et al., 2017; Murawska-Cialowicz et al., 2015), as well as a reduction in body fat percentage (Barbieri et al., 2019; Mangine et al., 2020; Perna et al., 2018). That could be explained by the increment in testosterone concentration, which has influences on metabolic and body composition (Isidori et al., 2005; Mudali & Dobs, 2004). Therefore, this evidence supports the implementation of CF programmes for the improvement of body composition.

Subjective adaptations

Subjective types of responses are measured with scales, questionnaires, surveys, and interviews, with the aim of recording the perception of effort, mood, and enjoyment of the session, among other things. Studies have shown very high RPE values after the session and very high levels of subjective fatigue after training that gradually decrease with experience (Butcher et al., 2015; Maté-Muñoz et al., 2018; Sánchez-Alcaraz & Gómez-Mármol, 2015). Users experience feelings of enjoyment (Sánchez-Alcaraz & Gómez-Mármol, 2015); however, in regard to mood, there is controversy in the literature, with some authors reporting an improvement in mood (Pereira et al., 2019) while others do not highlight such results (Drake et al., 2017). According to Drake et al. (2017), the higher volume and intensity of the training stimulus could explain the negative changes in the mood reflected. However, generally during and after a CF session, there is a high level of exertion, fatigue, and feelings of enjoyment and satisfaction.

When participants and athletes systematically repeat this type of training, terms such as «adherence», «fun when practising», «NPB satisfaction» and «motivation for participation», which are feelings that have been exposed by the authors of various studies of a descriptive type, can be discussed (Box et al., 2019; Heinrich et al., 2014, 2021; Marin et al., 2018). The differences between genders can also be highlighted as women seem to be more likely to place greater emphasis on factors related to stress, weight control, and appearance than men, and men placed more importance on factors associated with challenge, social recognition, competition and physical qualities (Bycura, Feito, & Prather, 2017). There are also other negative variables to mention, such as addiction to the sport, body dissatisfaction and eating disorders (Coyne & Woodruff, 2020; Freire et al., 2020; Wilke et al., 2020), which may be due to taking training to the extreme, and behaviours that may hide psychic pathologies (Di Lodovico, Poulnais, & Gorwood, 2019). These variables should be monitored to avoid their appearance in the CF practitioner.

Chronic adaptations and performance

Studies that have investigated chronic adaptations in physical qualities as a result of practising CF have reflected increases in range of motion (Tafuri et al., 2016) and strength levels (Costa & Andrés Santiago Parodi Feye, 2021). These authors have related good mobility to optimal force application due to good positioning of biological mechanical levers, the use of joint range of motion, and adjacent muscle structures (Simão, et al., 2011). As regards the variables that perform better in the WODs analysed by the studies, experience, strength, and power (especially lower-limb), as well as an optimal body composition, are the variables that mediate performance. On the other hand, contrary to previous studies, the percentage of fat and cardiorespiratory capacity were not significantly correlated with CF Open 2020 workout performance (Tibana et al., 2021). Therefore, it should be noted that experience seems to lead to an optimisation of technique, and gains in maximum strength and power that lead to improved performance.

Conclusion

This review presents the existing articles in the scientific literature that study the responses and adaptations experienced by subjects due to CF training. We conclude that acute response from CF involves a high physiological demand that drives performance loss in CMJ and reaction time. Likewise, this high intensity is perceived by participants, who report high scores on the RPE scale and describe a reduction in feelings such as will, depression, confusion, and tension immediately after ending training. Moreover, recreational athletes show an increase in pleasure whilst professionals feel anxiety.

With regard to chronic adaptation, athletes' expertise could have an influence on VO2max improvement. Likewise, obese adults could see benefits in their BP after a long period of CF training. Moreover, improvements in hormonal concentration have been found, which supported the enhancement of fat-free mass after four weeks of training. Furthermore, CF satisfies basic psychological needs and results in greater adherence than other sports, but it can be addictive. On the other hand, performance in CF could be influenced by the range of motion from the shoulder and lower-limb joints. Moreover, every type of WOD could have a different physiological profile, which determines the key to success for each modality of competition.

Practical application

CF aspects led to high adherence observed in these programmes, resulting in their implementation being recommended not only at a sporting level but also at training levels or with health objectives. It must not be forgotten that, despite all these positive points, the bad practice of this modality can lead to acute or chronic injuries, and image disorders, among other complications. To ensure that only the positive aspects appear, the prescription of this training format should be subjected to qualified people with advanced knowledge of training and athletic fitness in a modality as broad as CF.

Future research lines

Despite the evidence about CF, there are still concerns about this training that should be answered: (i) WOD profiles should be explored to adapt each training session according to the physiological demand; (ii) accumulated fatigue index should be studied as an overreaching index in CF athletes; moreover, (iii) due to the effects on adherence, adapted CF should be tested in people with chronic disease or a strong need for exercise.

Disclosure interest

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

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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