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Are extreme conditioning programmes effective and safe? A narrative review of high-intensity functional training methods research paradigms and findings

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ABSTRACT

Extreme conditioning programmes (ECPs, eg , CrossFit, Insanity and Gym Jones) are a growing fitness regimen characterised by functional movements performed at high-intensity and with constantly varying movements. While the popularity and number of practitioners of ECPs are growing, a debate has been established between what is observed in the scientific literature and anecdotal reports from athletes, coaches and physicians about safety (incidence and prevalence of injuries and rhabdomyolysis) and benefits (physical and mental health). In this article, we review the prevalence and incidence of injuries, rhabdomyolysis, physiological responses and chronic adaptations to ECPs. The majority of the available evidence confirm that the estimated injury rate among athletes participating in ECPs is similar to that in weightlifting and most other recreational activities. Additionally, ECP sessions resulted in increased acute oxidative, metabolic and cardiovascular stress, and depending on the stimulus (intensity, duration and non-usual exercise) and training status of the practitioner, an ECP session may precipitate rhabdomyolysis. In the scientific literature, the current chronic effects of ECPs showed little or no effects on body composition and improvements in physical fitness and psychological parameters; however, further studies are important.

Key messages

- Extreme conditioning programmes (ECPs, eg, CrossFit, Insanity and Gym Jones) are a growing fitness regimen characterised by functional movements performed at high-intensity and with constantly varying movements.
- The majority of the available evidence confirms that the estimated injury rate among athletes participating in ECPs is similar to that in weightlifting and most other recreational activities.
- ECP sessions resulted in increased acute oxidative, metabolic and cardiovascular stress, and depending on the stimulus (intensity, duration and non-usual exercise) and training status of the practitioner, an ECP session may precipitate rhabdomyolysis.

INTRODUCTION

A relatively new form of exercise referred to as 'extreme conditioning programmes' (ECPs) is currently being marketed to a wide, active (athletes, military) and inactive population. ECPs (eg, CrossFit, Insanity, Gym Jones and others) often consist of a variety of training methods such as resistance training with kettlebells and barbells, repeated gym bodyweight exercises, explosive movements, sprints and flexibility.[1–3] ECPs are characterised by a high training volume, including a variety of exercises performed at high-intensity and, often, at a fixed time to perform a number of repetitions or a specific task in the shortest possible time, with or without short rest periods between the series.[1–3] These exercises are vigorous and physically demanding. According to Glassman[4]—one of the founders of one type of world-renowned ECPs (CrossFit)—the goal with this type of training is to acquire a broad, comprehensive and inclusive fitness that will best prepare practitioners for any physical contingency.

Nowadays, these physical conditioning programmes are well-marketed and popularised, mainly due to their motivational and challenging character, which contributes to an exponential increase in the number of practitioners.[5 6] There is a great number of individuals performing this type of physical exercises, from apparently healthy to even obese individuals[7] or, as it is being popularised, by an adapted population. In addition, ECPs allow the participants to perform the exercises at locations other than gyms, also attracting individuals who are not adapted to traditional fitness centres.

However, the increased acceptance is reinforced through anecdotal reports of gains in

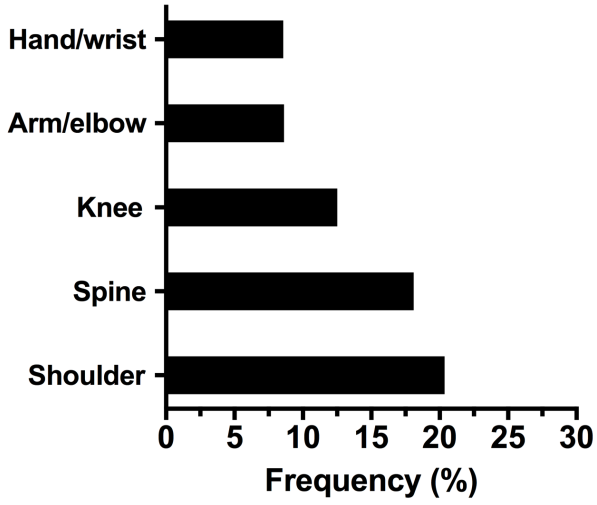

Figure 1 Summary of the most frequent injuries caused by extreme conditioning programmes reported by the different authors[10–15].

physical fitness and performance.[8] That is, there is still little scientific evidence to support the use of this type of programmes in the general population to improve physical fitness and health and, in addition, there are doubts about the safety of these exercises. Health benefits of ECPs are still underpinned by the integrated use of the most recent and major fitness trends, such as high-intensity interval training, group training, weight training, strength training and functional fitness,[9] which have demonstrated strong evidence of improved cardiovascular health and improved insulin sensitivity and dyslipidaemias, in addition to functional fitness. On the other hand, these training programmes raise concerns in society and future athletes regarding safety and likelihood of causing injuries or illnesses. In this sense, three issues have gained attention with respect the safety of ECPs, namely: (1) use of fast movements with a high number of repetitions and insufficient rest intervals; (2) participants with a weak motor repertoire to perform complex movements and (3) a possible lack of educated, certified and experienced ECPs professionals, especially in the integration of all training methods. In this article, we review the prevalence and incidence of injuries, physiological responses and chronic adaptations to ECPs.

Incidence and prevalence of injuries

Little has been reported regarding the incidence and prevalence of injuries sustained secondarily to participation in an ECPs. Moreover, what constitutes an injury during ECPs has not been clearly defined and each article defines injury differently. A common concept of injury among authors that have assessed the incidence and prevalence of injuries caused by ECPs is any physical complaint that was sustained during ECPs training that results in a participant being unable to take part fully in ECPs training (eg, a time loss definition) or modification of normal training activities in duration, intensity or mode.[10–14] In addition to the definition of injury, another difficulty found in the literature to establish a correct relationship between the practice of ECPs and injuries is the lack of information regarding the population studied, that is, the practice of ECPs by athletes/competitors or only by individuals whose goal is improving physical fitness and health. We emphasise the need of providing the correct description of samples in further studies, mainly because ECPs are increasingly being used by practitioners, whose goal is physical fitness and health, and athletes/competitors.

The first important conclusion about injuries in ECPs was described by Grier *et al*[3] and was related to the types of injuries. Injuries in ECPs ranged from overuse injuries (stress fractures and reactions, tendonitis, shin splints and general musculoskeletal pain from repetitive microtraumas) and traumatic injuries (resulting from sudden force or forces applied to the body).[3] The most frequent injuries caused by ECPs reported by the authors studied were those located in: shoulders; the spine, especially in the lumbar region; arms and elbows; hands and wrists; knees; hips and thighs; ankles; necks and chests and feet (figure 1).[10–16] Hak *et al*[13] affirm that the higher prevalence of shoulder injuries can be explained by their frequent submission to hyperflexion, internal rotation and abduction, placing the shoulders in a position of risk. Although the incidence of injuries is higher in the locomotor system, other injuries have been reported, such as retinal detachment and carotid dissection.[17 18] Tibana *et al*[19] have also pointed out the risk of exacerbated inflammatory response after ECPs.

There is a scarce number of studies in the literature addressing the incidence of injuries in practitioners of ECPs. Table 1 provides a summary of the injuries and descriptions provided in these studies. Klimek *et al*[20] state that the injury rate observed in ECPs is comparable or even lower than that caused by other common physical exercises or, even, strength training. However, Keogh and Winwood[21] assessed competitors of different modalities and found that Strongman training (4.5–6.1 injuries per 1000 hours) and Highland Games (7.5 injuries per 1000 hours) were the modalities with the highest injury rates, which were substantially higher than that of bodybuilders, who exhibited the lowest injury rate (0.24–1 injuries per 1000 hours). When all strength modalities were compared, the injury rate was approximately 1–2 injuries per athlete/year and 2–4 injuries per 1000 hours of training/competitions.[21] On the other hand, injury rates in sports such as football, rugby and cricket were 15–81 per 1000 hours of training/competitions. This way, when the incidence of injuries per 1000 hours of practice were assessed, the results observed in ECPs were smaller than those in sports such as rugby, football, volleyball, judo, tennis and cricket, which can exhibit rates of 15–81 injuries per 1000 hours of training/competitions.[21]

Some authors have attempted to establish relationships between injuries and characteristics of the trainings or the individuals. Grier *et al*[3] assessed the prevalence

Table 1 Summary of the ECPs injuries and description

Study	Type of ECPs	Participants	Study design	Study duration	Injuries (n)	Prevalence of injuries (%)	Incidence of injuries (injuries/1000 hours)
Aune and Powers[15]	Iron tribe fitness	247 iron tribe fitness athletes (139 men)	Prospective Online questionnaire	12 months	132	34	2.71
Grier *et al*[3]	ATAC, RAW, CrossFit	1393 US soldiers (1248 men) 26.8±5.9 years	Prospective Face-to-face questionnaire	12 months	–	41	–
Hak *et al*[13]	CrossFit	132 worldwide CrossFit participants (98 men) 32.3 (19–57) years	Prospective Online questionnaire	EC	186	73.5	3.1
Mehrab *et al*[14]	CrossFit	449 Dutch CrossFit participants (266 men) 31.9±8.3 years	Prospective Online	12 months	252	56.1	–
Montalvo *et al*[10]	CrossFit	191 South Florida CrossFit participants (94 men) 31.7±9.4 years	Prospective Face-to-face questionnaire	6 months	62	26.2	2.3
Moran *et al*[11]	CrossFit	117 UK CrossFit participants (66 men) 35±10 years	Prospective Face-to-face questionnaire	12 weeks	15	–	2.1
Summitt *et al*[44]	CrossFit	187 US CrossFit participants	Prospective Online Shoulder injuries only	6 months	46	23.5	1,94
Weisenthal *et al*[12]	CrossFit	386 US CrossFit participants (231 men)	Prospective Online	6 months	74	19.4	2.4

ATAC, Advanced Tactical Athlete Conditioning; EC, entire career; ECPs, extreme conditioning programmes ; RAW, Ranger Athlete Warrior.

of injuries in American soldiers after the implementation of a ECPs in physical preparation routines before and after 6 months. The main reasons for the injuries (12% of individuals injured) were low cardiorespiratory fitness, overweight/obesity and being smoker. In addition, it was observed that soldiers, both practitioners and non-practitioners of ECPs, who already had a habit of practising strength training, exhibited a lower incidence of injuries. Weisenthal *et al*[12] found a significantly higher incidence of ECPs-related injuries in men than in women. One explanation for such a difference was the greater demand of female athletes for CrossFit coaches. Factors such as proper use of load, correct execution of movement patterns and prioritisation of the technique rather than the performance to be achieved have been mentioned as important elements for the reduced rate of injuries in women. According to Montalvo *et al*,[10] higher training volume and greater height and body mass were related to a higher incidence of injuries, which probably generated an increase in the load used during training routines. Among adults, different age groups did not exhibit a significant variation in the risk of injuries. This fact indicates that, in a safe and properly monitored environment, ECPs can function properly for adult and older athletes in all age groups.[12] We cannot state the same conclusion for young practitioners because the lack of data; however, considering the correct monitored environment and the learning potential of new motor tasks, we can suppose the low risk of injuries among young practitioners. Finally, Mehrab *et al*[14] observed that a short duration of participation (<6 months) in ECPs was significantly associated with an increased risk for injury.

Exertional rhabdomyolysis

Rhabdomyolysis is a syndrome characterised by muscle necrosis followed by the release of intracellular muscle contents into the circulation. When rhabdomyolysis occurs due to exercise, it is termed 'exertional rhabdomyolysis'. Exertional rhabdomyolysis occurs in response to non-familiar and/or excessive, prolonged or repetitive exercises, with eccentric characteristics.[22]

Nowadays, with the rapid expansion of ECPs, reports of rhabdomyolysis have also increased (table 2). Pearcey *et al*[23] reported the occurrence of rhabdomyolysis in an athlete who, after 3 months without training, initiated the practice of high-intensity sports in a sudden and intense manner. According to the authors, the athlete's subjective notion of myalgia was impaired due to intense motivation and the use of pre-workout supplement. Meyer *et al*[24] emphasised the seriousness of rhabdomyolysis and reported its occurrence in a previously healthy 31-year-old woman. Despite being a regular practitioner who performed exercises four times a week, she exhibited the syndrome after the first CrossFit training. The authors also argued that myoglobinuria and myalgia were not mandatory findings, given that only 50% of the cases exhibited the characteristic exacerbated muscular pain. This is why the main diagnostic criterion is based on laboratory quantification of creatine kinase (CK). Additionally,

Table 2 Summary of the ECPs induced rhabdomyolysis

Study	Type of ECPs	Subject	Study design	Physical status	Protocol of ECPs
Hadeed *et al*[45]	CrossFit	Man	Case report	He reports having had five previous days of exercise but did not involve CrossFit type training.	Non-informed.
Pearcey *et al*[23]	Non-informed	Man	Case report	Athlete who was acutely detrained (approximately 3 months).	48 alternating sets (60 s duration) of push-up and pull-up variations. The subject performed the maximum number of repetitions possible of push-ups or pull-ups in each set. The total exercise duration was 48 min. The subject performed approximately 400 push-ups and approximately 200 pull-ups in 48 min.
Wagner *et al*[46]	Non-informed	Woman	Case report	A healthy 21-year-old Caucasian woman was participating in an organised, extreme exercise workout session conducted at a fitness centre.	The exercise session consisting of performing a designated number of push-ups in 1 min. The protocol dictated 5 push-ups in the first minute, 10 in the second and adding 5 push-ups each minute until participants can no longer continue. She recalls completing 6 rounds of increasing repetitions in each minute, thereby performing 105 push-ups in 6 min.
Lozowska *et al*[25]	CrossFit	Five of six patients were women	Case series	Three of the six patients were very physically fit before experiencing rhabdomyolysis, having participated in CrossFit for months to years. The remaining three patients were less fit and sustained rhabdomyolysis after their first encounter with CrossFit.	Non-informed.
Aynardi and Jones[47]	Non-informed	A 43-year-old African American woman	Case report	She was healthy overall and had been active in multiple gym-related exercise programme over the past 10 years.	The ECPs consisted of a standard warm-up followed by 3 sets of chin-ups that were performed until 'failure' lasting approximately 20 min.
Meyer *et al*[24]	CrossFit	A previously healthy 31-year-old woman	Case report	She was exercising regularly four times per week, performing push-ups, running and other physical workouts.	The subject denied recent trauma or illness but reported performing a variety of high-intensity exercises such as push-ups,
Honda *et al*[48]	Non-informed	A previously healthy 37-year-old man	Case report	He had exercised regularly but had never performed such intense training before.	Intense exercise training that included 100 push-ups, 100 exercises using a 20 kg dumbbell, 50 lifts using a 10 kg weight.
Routman *et al*[49]	CrossFit	Two previously healthy women; 36 years (case 1) and 37 years (case 2)	Case report	Case 1. A 27-year-old healthy woman with a BMI of 22 kg/m^2. She was a long-distance runner with no noteworthy medical or surgical history and was not taking any medications; Case 2. A healthy 26-year-old woman with a BMI of 34 kg/m^2	The two cases of isolated infraspinatus rhabdomyolysis following exertional overuse after a challenge known as the 'Sissy Test'. This challenge involves up to 336 kettlebell swings and 336 squat-thrust push-ups (also known as 'burpees') in an allotted time frame of 30 min. Beginning with 15 kettlebell swings and 1 burpee, the workout challenge is repeated with a descending number of kettlebell swings and a corresponding ascending number of burpees. This is continuously repeated until the final set of 1 kettlebell swing and 15 burpees has been performed.
Tibana *et al*[27]	Extreme conditioning competition	A 35-year-old woman without medical history of disease	Case report	She was healthy overall and had been active in ECPs over the previous 5 years and trained 4–5 times per week.	ECPs competition lasting 2 days and composed of five workouts. One workout consisted of 60 repetitions for an unaccustomed exercise (GHD).

BMI, body mass index; ECPs, extreme conditioning programmes; GHD, glutes-hamstring developer.

in a study conducted with a greater number of cases, Lozowska *et al*[25] reported six events of rhabdomyolysis associated with CrossFit practice. Previously healthy patients—some of them with considerable experience with the modality and no family history—had exhibited manifestations such as exacerbated myalgia after the first 24 hours of training, especially in the muscular regions which were more vigorously demanded during

the exercise. Half of them had good physical fitness before the event, having practised the modality from months to years. It should be noted that the onset of clinical manifestations does not occur immediately after physical exertion, as reported by Larsen *et al*,[26] who found that signs and symptoms had only appeared 3 days after the training that had given rise to the condition. Recently, Tibana *et al*[27] described an instance of exercise-induced rhabdomyolysis, caused by an ECPs competition, in a 35-year-old woman who presented with abdominal pain and soreness, which began 1 day after she had completed 2 days of an ECPs competition composed of five workouts. Interestingly, although she had more than 5 years of experience in ECPs, during the competition, one workout consisted of 60 repetitions of glutes-hamstring developer (unaccustomed exercise) that precipitated the rhabdomyolysis.

These results indicate that coaches and trainers of ECPs should be aware of the risk and should maybe consider prescribing lower volume and intensity sessions in non-usual exercises to minimise the risk of rhabdomyolysis (including in the weeks before a competition). The inclusion of unaccustomed exercise with volume and intensity similar to a competition will induce cellular protection; this phenomenon is known as the 'repeated bout effect'. Finally, we must rethink current ECPs strategies to improve athletic performance, because unfortunately exertional rhabdomyolysis is becoming increasingly more prevalent in ECP practitioners. We believe that the periodisation of the programme, taking into account the progressive increase in volume and intensity in non-usual exercises, could be the best way to prevent certain undesired events, such as rhabdomyolysis.

Physiological responses to an extreme conditioning programmes session

The physiological demands during ECPs have been quantified via the measurement of heart rate (HR),[19] blood lactate concentration,[28] catecholamines and cytokines.[28] The results are described in table 3. During ECPs, the HR_{max} percentage measured during the short session (<5 min) was 92.7%±4%, while the long session (15 min) elicited a 91.3%±3% HRmax.[29] Tibana *et al*[19] and Kliszczewicz *et al*[30] reported in trained men that immediately postexercise HRs were almost always above 80% HRmax. Interestingly, Tibana *et al*[19] showed that the ECPs employing Olympic weightlifting exercises during the metabolic condition induced a higher increase in HR (86%±11% of HRmax) compared with an ECPs session without Olympic weightlifting exercise (82%±12% of HRmax).

Blood lactate concentration values measured after ECPs have provided evidence of high metabolic involvement in this programme. Immediate postexercise sampling revealed very high values in both trained and untrained practitioners, ranging from 9.0±2.5 mmol/L to 17.8±4.9 for trained to 14.2±2.3 mmol/L for untrained (table 3). Nonetheless, the session duration does not implicate in different metabolic response, as reported by Kliszczewicz *et al*[29] and Maté-Muñoz *et al*.[31] Figure 2 shows a summary of blood lactate concentration, rating of perceived exertion (RPE) and HR responses presented in the available papers related to ECPs.

In terms of the hormonal and cytokine responses after ECPs, Kliszczewicz *et al*[29] demonstrated significant elevations of plasma epinephrine (685%±601%, 620%±358%) and norepinephrine (779%±313%, 736%±271%) immediately postexercise following short and long sessions of ECPs; however, the authors found no difference between the short and long ECP sessions in terms of catecholamine concentrations. Heavens *et al*[32] noted a transient change of testosterone (~25 nmol L^{-1} in men) and cortisol (mean±SD men: 1,247.4±364.0 nmol L^{-1}; mean±SD women: 985.2±438.1 nmol L^{-1}), with the highest mean values observed at 15 min postexercise. However, 24 hours postexercise, these values were normalised. With regard to the cytokine response, Tibana *et al*[28] found that training sessions of ECPs elicited significant increases in interleukin (IL)-6 (session 1: 197%±109% and session 2: 99%±58%), IL-10 displayed an increase immediately after session 1 (44±52%) and decreased 24 and 48 hours following session 2, and although not statistically significant, IL-10/IL-6 decreased 24 hours (~50%) and 48 hours (~50%) after session 2 when compared with baseline. Similarly, Heavens *et al*[32] showed that a high-intensity with a short-rest protocol (which consisted of a descending pyramid scheme of back squat, bench press and deadlift, beginning with 10 repetitions of each, then 9, then 8 and so on until 1 repetition on the final set) elicits a significant increase in inflammation (IL-6 immediately postexercise for men:~3 pg/mL; women:~3.5 pg/mL).

These results indicate that ECPs elicited a higher metabolic, cardiovascular, hormonal and inflammation response. Therefore, strength and conditioning professionals need to be aware of the level of stress imposed on individuals when performing metabolic workouts of ECPs. While future research is needed to determine the significance of this result, it is recommended that the incorporation of lower intensity sessions (eg, through the rating of perceived exertion or HR) and/or resting days would help to minimise this exacerbated physiological response.

Chronic adaptations to extreme conditioning programmes

Current ECP studies that investigated the chronic effects are based on changes in body composition, fitness and psychophysiological parameters in both sedentary and physically active participants. Heinrich *et al*[7] evaluated the body composition of eight sedentary men and eight sedentary women after 8 weeks of ECPs training and no significant changes were observed in body mass index, fat mass or lean body mass. Despite the unchanged

Table 3 Physiological responses to an extreme conditioning programme session

Study	Type of training	Subjects	Protocol of ECPs	Lactate (mmol L^{-1})	HR	RPE
Tibana *et al*[28]	ECP	Trained men	Protocol 1—10 min AMRAP of: 30 double-unders and 15 reps of power snatches (34 kg). Protocol 2—12 min AMRAP of: Row 250 m 25 6″ Target Burpees	1=IPE—11.8±1.3 2=IPE—9.0±2.5	–	–
Szivak *et al*[50]	High-intensity functional training	Untrained women/men	The protocol consisted of the back squat, bench press and deadlift exercises, beginning with 10 repetitions of each exercise, respectively. Each set decreased by 1 repetition until the final set of a single repetition (descending pyramid scheme), for example, 10 repetitions of back squat, 10 repetitions of bench press and 10 repetitions of deadlift, followed by 9 repetitions of back squat, 9 repetitions of bench press and 9 repetitions of deadlift. This repetition scheme continued until 1 single repetition of each exercise was performed on the final circuit. The weight used for the exercise protocol was set at 75% of the subject's previously established 1RM in each exercise.	Men=IPE—14.2±2.3 Women=IPE—9.1±2.2	Men=peak values of 191 bpm. Women=peak values of 190 bpm.	Men=estimated mean during all protocol ~8 Women=estimated mean during all protocol ~8
Maté-Muñoz *et al*[31]	CrossFit	Trained men	Protocol 1—'Cindy' which involves executing the greatest number of sets of 5 pull-ups, 10 push-ups and 15 air squats (bodyweight squats) in 20 min. Protocol 2—The WOD consisted of conducting the maximum number of double unders possible in 8 sets of 20 s with 10 s of rest between sets. Protocol 3—The maximum number of power cleans (Olympic lifts) was executed lifting a load equivalent to 40% of the individual's 1RM during 5 min.	1=IPE—11.7±2.3 2=IPE—10.1±3.0 3=IPE—11.2±2.6	–	–
Tibana *et al*[19]	ECP	Trained men	Protocol 1—10 min AMRAP of: 30 double-unders and 15 reps of power snatches (34 kg). Protocol 2—12 min AMRAP of: Row 250 m 25 6″ Target Burpees	–	1=IPE—86%±11% of HRmax 2=IPE—82%±12% of HRmax	1=IPE—8.8±1.2 2=IPE—8.0±1.2
Kliszczewicz *et al*[29]	High-intensity functional training	Trained men	Protocol 1—The workout 'Grace' that consists of 30 power clean & jerks at 61.4 kg using an Olympic barbell. Protocol 2—AMRAP of 250 m row on a rowing ergometer (Concept 2), 20-kettlebell swings at 16 kg and 15-dumbbell thrusters with two 13.6 kg dumbbells.	1=IPE—14.3±2.0 2=IPE—3.7±1.5	1=AVG—92.7%±4% of HRmax. 2=AVG—91.3±3% of HRmax.	–
Perciavalle *et al*[51]	CrossFit	Trained men	Protocol—For time: 27-21-15-9 repetitions in term of Row (calories) and Thrusters, by using a rowing ergometer and a barbell	IPE—13.8±1.2	–	–
Kliszczewicz *et al*[30]	CrossFit	Trained men	Protocol—'Cindy' which involves executing the greatest number of sets of 5 pull-ups, 10 push-ups and 15 air squats (bodyweight squats) in 20 min.	–	IPE=97.7%±1.9% of HRmax	IPE=9.0±0.3

Continued

Table 3 Continued

Study	Type of training	Subjects	Protocol of ECPs	Lactate (mmol L^{-1})	HR	RPE
Tibana *et al*[52]	High-intensity functional training	Trained men	Protocol 1—'Fran' is characterised by couplet barbell thrusters (a front squat to push press) and pull-ups following a 21–15–9 repetition scheme, where 21 thrusters were completed, then 21 pullups completed, 15 thrusters and 15 pull-ups, 9 thrusters and 9 pull-ups completed for time. Variations of pullups, including butterfly and kipping, were encouraged. Thrusters were performed with 43.2 kg Protocol 2—The 'Fight Gone Bad' (FGB) comprises three rounds of Wall-ball (9 kg), Sumo deadlift high-pull (34 kg) Box Jump (50 cm), Push-press (34 kg) and Row (Calories). In this training session, subjects moved from each of five stations after a minute. The clock did not reset or stop between exercises. This is a 5 min round from which a 1 min break was allowed before repeating.	1=IPE—17.8±4.9 2=IPE—17.2±3.5	1=IPE—182.0±5.2 bpm. 2=IPE—184.4±4.1 bpm.	1=IPE—8.7±0.8 2=IPE—9.6±0.5

AMRAP, as many reps as possible; AVG, average; BPM, beats per minute; HRmax, heart rate maximum; IPE, immediately postexercise; RPE, rating of perceived exertion; WOD, workout of the day.

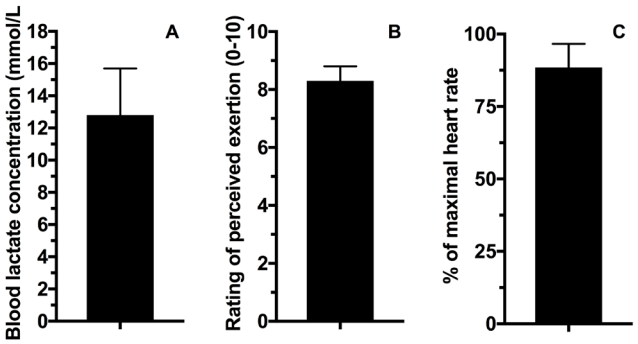

Figure 2 Summary of blood lactate concentration, rating of perceived exertion and heart rate responses presented in the available papers related to extreme conditioning programmes[19 28–31 50–52].

body composition, participants were able to maintain exercise enjoyment and were more likely to have the intention of continuing. Murawska-Cialowicz *et al*[33] also observed no change in body mass index after 12 weeks of ECPs training in seven physically active men and five physically active women. However, lean body mass increased for both groups and body fat decreased only for women. Women also presented a reduction in waist circumference.[33] Murawska-Cialowicz *et al*[33] also showed an increase in VO_{2max} for women, which was not observed in men, and no improvements were seen in the blood profile of 11 college students (six men) after 14 weeks of ECPs training.[34] Similar results were achieved by Sobrero *et al*[35] on body composition (no changes in fat mass and little increase in body mass) after 6 weeks of ECPs training. Sobrero *et al*[35] also found no changes in maximal oxygen uptake (VO_{2max}), anaerobic power and flexibility. The impact of at least 6 months of ECPs training on pelvic floor muscle strength and support in nulliparous healthy women was evaluated by Middlekauff *et al*.[36] Chronic ECPs training demonstrated neither beneficial nor deleterious effects on pelvic floor strength or support.

Chronic effects of ECPs training were also evaluated in teens and unhealthy adults. Heinrich *et al*[37] evaluated cancer survivors (n=6; sedentary) after 5 weeks' ECPs and observed significant improvements in lean body mass, fat mass, lower body strength and power, aerobic capacity and balance. Moreover, the cancer survivors showed improvements in emotional functioning and perceived difficulty in flexibility. Adults with type 2 diabetes (n=12) also decreased body fat and abdominal body fat, whereas lean body mass was preserved after 6 weeks of ECPs training.[38] ECPs training also improved insulin sensibility and ß-cell function after intervention. With regard to teens, Eather *et al*[39] demonstrated improvements in waist circumference and body mass index and performance tests (flexibility, power and cardiorespiratory fitness) in 51 physically active teenagers after 8 weeks of ECPs training. Eather *et al*[39] also demonstrated high retention (82%) and

adherence (94%) rates to ECPs training. ECPs practice during physical education lessons has shown high levels of enjoyment, effort and learning perception in the students (n=104) after 8 weeks of training.[40] On the other hand, Eather *et al*[41] showed that 8 weeks of ECPs training by teens did not improve mental health outcomes in all the students (n=51). However, in adolescents 'at risk' of developing psychological disorders, ECPs training improved mental health. Last, Ward *et al*[42] showed significant improvements in the progressive aerobic cardiovascular endurance run, push-ups and curl-ups tests of the FITNESSGRAM and health-related fitness knowledge after 20 lessons of ECPs in 166 fifth-grade students (76 boys, 90 girls). To date, current chronic effects of ECPs scientific literature showed little or no effects on body composition and improvements in physical fitness and psychological parameters; however, further studies are important. Figure 3 shows

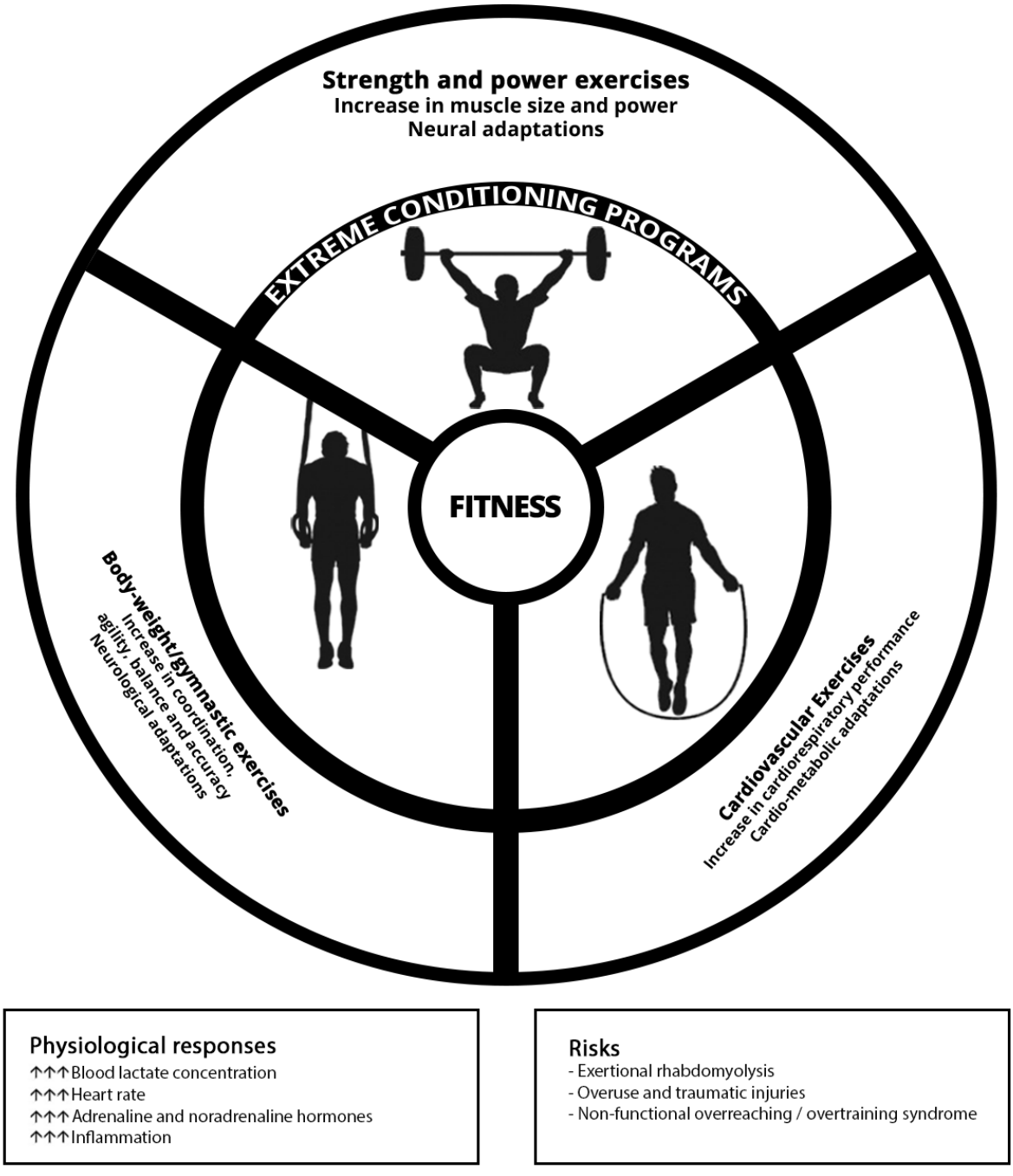

Figure 3 Extreme conditioning programme characteristics, possible chronic adaptions of each foundational modalities, physiological responses and potential risks.

a summary of the ECP characteristics, possible chronic adaptions of each foundational modalities, physiological responses and potential risks.

Psychological effects of ECPs are yet less studied. However, based on the rapid growth and popularity of the programme, it is apparent that ECPs provide an appealing fitness option for many individuals. Sibley and Bergman[43] state that several specific aspects of the ECPs are noteworthy in their potential impact on goal contents and basic psychological need satisfaction. Applying these aspects in exercise contexts, in general, may facilitate participants' autonomous motivation and increase participation levels. Sibley and Bergman[43] also showed that ECP participants primarily strive for goals related to health management and skill development, with physique enhancement and social affiliation being of secondary importance. Social recognition was the lowest rated goal. On the other hand, Lichtenstein *et al*[5] showed that the prevalence of exercise addiction in CrossFit was 5% and was similar to the prevalence rates in other sport populations.

CONCLUSION

The majority of the available evidence presented in this paper confirms that the estimated injury rate among athletes participating in ECPs is similar to the rate of injury in weightlifting and most other recreational activities. Additionally, ECP sessions resulted in increased acute oxidative, metabolic and cardiovascular stress, and depending on the stimulus (intensity, duration or non-usual exercise) and training status of the practitioner, an ECPs session may precipitate rhabdomyolysis. There is an alarming increase in case reports of rhabdomyolysis after ECPs. Current ECP studies that have investigated the chronic effects are based on changes in body composition, fitness and psychophysiological parameters in sedentary and physically active participants. The ECPs scientific literature showed few or no chronic effects on body composition and improvements in physical fitness and psychological parameters; however, further studies are important.

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