



Physiological Responses to CrossFit Training: Evaluation of Aerobic Endurance through Cardiopulmonary Exercise Testing

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Abstract

Background. CrossFit is a high-intensity training method involving varied functional movements that is potentially effective for improving aerobic endurance.

Objectives. This study used a mixed-methods approach to evaluate the effects of a structured CrossFit programme on cardiorespiratory fitness, combining objective measurements with the athletes' subjective perceptions.

Materials and Methods. A total of 80 regular exercisers (aged 20–35) were divided into an experimental group (CrossFit) and a control group (weight training). A quantitative assessment was conducted using cardiopulmonary exercise testing (CPET) at two time points (T0 and T1, after 12 weeks), analysing VO₂ max, ventilatory threshold and heart rate response to submaximal loads. In parallel, semi-structured interviews were conducted at the end of the intervention and analysed using thematic analysis.

Results. The results showed greater improvements in the CrossFit group than in the control group, with an average increase in VO₂ max of +8.2% vs. +1.9%, an increase in ventilatory threshold of +6.4% vs. +1.1%, and a reduction in heart rate at the same load of –3.7% vs. –0.9%, respectively.

Conclusions. The interviews confirmed better fatigue management, more efficient breathing, and the transfer of benefits to daily activities. Therefore, the findings indicate that a 12-week CrossFit programme appears to promote significant cardiorespiratory adaptations, consistent with the athletes' perceptions.

Keywords: CrossFit, aerobic endurance, VO₂max, cardiopulmonary exercise testing, high-intensity training.

Introduction

CrossFit is a sport that originated in the early 2000s. It aims to develop various motor skills simultaneously, including strength, power, agility, coordination and cardiovascular endurance (Dawson, 2017). It is a training method based on constantly varied functional movements performed at high intensity. The discipline's fundamental principles include variety of stimuli, the importance of intensity in adaptation, and the functionality of movements, which are often inspired by everyday gestures (Glassman, 2003; Claudino et al., 2018). This combination makes

CrossFit a comprehensive workout that engages multiple physiological systems in a coordinated manner, making it suitable for individuals with varying degrees of physical fitness (Meyer et al., 2017).

In recent years, there has been a significant increase in scientific attention regarding CrossFit, particularly with regard to its impact on cardiorespiratory capacity (Feito, et al., 2018). Aerobic endurance plays a central role among the physical abilities that can be trained through this discipline, as many workouts involve prolonged or repeated efforts over time characterised by high metabolic demand. Aerobic endurance is the body's capacity to sustain moderate or high-intensity physical activity over an extended period, thanks to the efficient utilisation of oxygen by the muscular, respiratory, and cardiovascular systems (Bassett & Howley, 2000).

A widely used benchmark for assessing aerobic endurance is maximum oxygen consumption ($\text{VO}_2 \text{ max}$), which is an indicator of the body's maximum capacity to transport and use oxygen during exercise. Measuring $\text{VO}_2 \text{ max}$ provides accurate information on cardiorespiratory efficiency and training-induced adaptations. In this context, cardiopulmonary exercise testing (CPET) is the most reliable and detailed tool for objectively assessing aerobic performance (Balady et al., 2010).

CPET (Cardio-Pulmonary Exercise Testing) is a functional assessment that simultaneously analyses the responses of the cardiovascular, respiratory and metabolic systems during incremental physical exercise. The test can be performed on a treadmill or cycle ergometer according to standardised protocols involving a progressive increase in workload until voluntary exhaustion is reached. Throughout the test, physiological parameters such as oxygen consumption (VO_2), carbon dioxide production (VCO_2), pulmonary ventilation, heart rate and blood pressure response are continuously monitored. This allows an integrated assessment of the body's ability to adapt to exertion to be made (Wasserman et al., 1987). As well as determining $\text{VO}_2 \text{ max}$, CPET enables significant physiological thresholds to be identified, such as the ventilatory or anaerobic threshold. This provides valuable information on tolerance to exertion and exercise duration over time (Beaver et al., 1986). This information is particularly useful in high-intensity disciplines such as CrossFit, where alternation between aerobic and anaerobic phases requires high metabolic adaptability.

Therefore, the application of cardiopulmonary testing in a CrossFit training context allows for the objective quantification of physiological adaptations induced by a structured intervention, while also providing insight into the subjective experience of athletes. Integrating quantitative and qualitative data enables us to understand not only whether measurable improvements exist, but also how athletes perceive and apply these changes to their daily activities (Plano Clark & Creswell, 2008).

Materials and Methods

Description of the Study

The study was conducted using a mixed-methods approach, which integrated quantitative and qualitative analysis tools in order to obtain a comprehensive assessment of the effects of CrossFit training on aerobic endurance. The integration of objective and subjective data made it possible to examine not only the physiological changes caused by training, but also the athletes' personal perceptions of the changes they experienced during sports activities and in their daily lives, in accordance with the principles of mixed research in motor sciences (Plano Clark & Creswell, 2008).

The quantitative assessment of aerobic endurance was performed using the cardiopulmonary exercise test (CPET), considered the gold standard for the combined analysis of cardiovascular, respiratory, and metabolic responses during physical activity (Beaver et al., 1986). The test was administered at two different times, at time T0, before the start of the CrossFit training program, and at time T1, at the end of the intervention, according to a pre-post repeated measures design. During the test, participants were continuously

monitored using a breath-by-breath respiratory gas analysis system, which allowed the detection of key physiological parameters, including oxygen consumption (VO_2), carbon dioxide production (VCO_2), pulmonary ventilation (VE), and respiratory quotient (RER). At the same time, heart rate and blood pressure response were recorded in accordance with international guidelines for CPET (Forman et al., 2010).

The main parameter taken into consideration to assess aerobic endurance was maximum oxygen consumption ($\text{VO}_2 \text{ max}$), alongside other indicators obtained from the test, such as ventilatory thresholds, which help to describe exercise tolerance and aerobic metabolism efficiency (Beaver et al., 1986). The comparison of the values obtained at T0 and T1 allowed for the analysis of any cardiorespiratory adaptations induced by the training intervention.

The qualitative analysis was conducted through semi-structured interviews with participants at the end of the training program. The choice of this tool is justified by the need to examine in depth the athletes' subjective perceptions of the effects of CrossFit on their aerobic endurance and bodily experiences during training, as indicated by the qualitative approaches used in motor sciences (Sparkes & Smith, 2013). The interviews were conducted using a predefined set of open-ended questions, which ensured a certain degree of uniformity in data collection while leaving room for personal experiences and individual meanings to emerge. The main themes explored included the perception of fatigue during training, the ability to sustain prolonged effort, perceived changes in breathing and intensity management, and the possible transfer of improvements to everyday life (e.g., during activities such as brisk walking or climbing stairs). The interviews were audio-recorded, transcribed in their entirety, and analyzed using a thematic analysis method, widely used for the interpretation of qualitative data in the context of sports and motor activities (Braun & Clarke, 2006). The integration of qualitative results with quantitative data allowed for a more complete and contextualized reading of the effects of CrossFit on aerobic endurance.

Participants

The study was conducted at a sports association offering CrossFit and traditional resistance-training programmes in Naples, Italy. The final sample consisted of 80 participants, divided into an experimental CrossFit group ($n = 40$) and a traditional resistance-training control group ($n = 40$), consistent with previous studies comparing high-intensity functional training and conventional strength-training modalities (Feito et al., 2018; Claudino et al., 2018). All participants completed both the baseline cardiopulmonary exercise test at T0 and the post-intervention assessment at T1 and were therefore included in the final analysis.

The total sample included 34 women (42.5%) and 46 men (57.5%), with a mean age of 27.5 ± 4.0 years and an age range of 20–35 years. The CrossFit group included 18 women (45.0%) and 22 men (55.0%), with a mean age of 27.2 ± 4.0 years. The control group included 16 women (40.0%) and 24 men (60.0%), with a mean age of 27.8 ± 4.1 years. No statistically significant differences were observed between the groups in age ($p = .510$) or sex distribution ($p = .651$), indicating demographic comparability at baseline. The selected age range is commonly considered appropriate for

investigations of cardiorespiratory performance in trained adult populations (Bassett & Howley, 2000).

Participants were not randomly assigned to the study groups. Group allocation was based on the training modality habitually practised during the study period. Participants in the experimental group followed a structured CrossFit programme, whereas participants in the control group followed a traditional resistance-training programme focused primarily on weightlifting and without structured metabolic-conditioning or continuous aerobic-training components. Consequently, the study adopted a quasi-experimental, non-randomised pre-post design, consistent with the methodological approach used in previous research comparing high-intensity functional and resistance-training programmes (Feito et al., 2018; Claudino et al., 2018).

The inclusion criteria were: (a) age between 20 and 35 years; (b) regular participation in the respective training modality; (c) at least four years of continuous experience in CrossFit or traditional resistance training; (d) possession of a valid medical certificate confirming eligibility for competitive or non-competitive sport; and (e) absence of cardiovascular, respiratory or musculoskeletal conditions contraindicating high-intensity exercise. Requiring at least four years of previous training experience was intended to ensure adequate familiarity with the intensity and technical structure of the exercises and to reduce the potential influence of motor-learning effects on test performance (Lopez, 2026). Medical eligibility and health screening were established in accordance with international recommendations for exercise testing and participation in high-intensity physical activity (American College of Sports Medicine [ACSM], 2018).

The mean training experience was 5.9 ± 1.1 years in the CrossFit group and 5.7 ± 1.0 years in the control group, with no statistically significant between-group difference ($p = .397$). This finding indicated that the two groups were also comparable in terms of previous exposure to structured physical training.

Participants were excluded if they reported an injury during the six months preceding enrolment, a health condition that could interfere with cardiopulmonary exercise testing, use of medications capable of substantially altering cardiovascular responses to exercise, or participation in other structured endurance-training programmes during the intervention period. The exclusion of participants with current or recent musculoskeletal injuries was consistent with recommendations aimed at reducing health risks and potential measurement bias in high-intensity exercise research (Weisenthal et al., 2014). Participants attending fewer than 50% of the scheduled sessions or failing to complete either the T0 or T1 assessment were also excluded from the final analysis. The minimum attendance criterion was established to ensure sufficient exposure to the intervention and adequate reliability in the interpretation of training-related adaptations (Feito et al., 2018).

During the 12-week intervention, both groups completed a maximum of 24 scheduled sessions. Participants in the CrossFit group completed an average of 22.1 ± 1.3 sessions, corresponding to an attendance rate of $92.1 \pm 5.5\%$, whereas participants in the control group completed 21.8 ± 1.5 sessions, corresponding to an attendance rate of $90.8 \pm 6.2\%$. Attendance did not differ significantly between the groups ($p = .324$), suggesting that differences in the

physiological outcomes were unlikely to be attributable to unequal exposure to the training programmes.

An age subgroup analysis was not conducted because the study was designed to examine the overall differences between the two training groups rather than group-by-age interactions. Dividing the sample into narrower age categories would have substantially reduced the number of participants in each subgroup, resulting in insufficient statistical power and potentially unstable estimates. Moreover, the 20–35-year inclusion range represented a relatively homogeneous young-adult population from a physiological perspective. Age was therefore analysed as a continuous baseline variable and considered when interpreting the generalisability of the findings.

All participants received detailed written and verbal information regarding the objectives, procedures, potential risks and expected benefits of the study. Written informed consent was obtained before data collection. The study was conducted in accordance with the ethical principles for research involving human participants and with the Declaration of Helsinki (World Medical Association, 2013).

Activities

Two supervised training programmes were implemented: a high-intensity functional training programme for the experimental CrossFit group and a traditional resistance-training programme for the control group. Both interventions were conducted at the same sports association in Naples, Italy, over a period of 12 weeks. Each group completed two 60-minute sessions per week, corresponding to a maximum of 24 training sessions. Sessions were scheduled on non-consecutive days, with an interval of at least 48 hours between consecutive sessions, to allow adequate recovery.

To facilitate supervision and maintain an appropriate instructor-to-participant ratio, the participants in each group were organised into four subgroups of 10 individuals. Each session was supervised by two qualified instructors holding a degree in exercise and sport sciences and possessing at least five years of professional experience in CrossFit or resistance training. The same instructors supervised each subgroup throughout the intervention to reduce variability in programme delivery.

Before the intervention, the instructors received a standardised programme manual describing the exercise sequence, session duration, prescribed intensity, loading ranges, recovery intervals, progression criteria and permitted exercise adaptations. Attendance, completed exercises, training loads, individual modifications and any adverse symptoms were recorded in an individual training log at the end of each session.

CrossFit training programme

The experimental group followed a structured CrossFit programme based on constantly varied functional movements performed at moderate-to-high intensity. The programme combined resistance and weightlifting exercises, body-weight gymnastic movements and metabolic-conditioning activities, in accordance with the principles of CrossFit and high-intensity functional training (Glassman, 2003; Feito et al., 2018).

Each 60-minute session consisted of:

1. a 10-minute general warm-up;
2. 15 minutes of technical preparation and specific activation;
3. a 12–15-minute Workout of the Day;
4. 10 minutes of cool-down and stretching.

The remaining 10–13 minutes were used for exercise explanation, equipment preparation, transitions between activities, hydration and individual adjustment of exercise loads.

General warm-up

The general warm-up was designed to progressively increase body temperature, activate the cardiovascular system and prepare the joints and muscle groups involved in the main workout. It included dynamic mobility exercises for the ankles, knees, hips, thoracic spine and shoulders, combined with low- to moderate-intensity activities such as jumping jacks, running on the spot, high knees, body-weight squats, dynamic lunges and arm rotations.

The activities were organised as two circuits of five exercises. Each exercise was performed for 30–40 seconds, with approximately 15 seconds allowed for transition between exercises. Warm-up intensity corresponded to approximately 3–4 on the 0–10 rating of perceived exertion scale. This phase promoted neuromuscular activation and progressive cardiovascular preparation before high-intensity exercise (Fradkin et al., 2010). The gradual organisation of the session was also intended to promote safe participation, engagement and social interaction among participants (Di Palma et al., 2025).

Technical preparation and specific activation

The technical phase focused on the movements included in the subsequent WOD. Participants performed core-activation exercises, scapular-stability exercises and dynamic lower-limb activation, followed by technical progressions of the principal weightlifting and gymnastic movements.

Squats, deadlifts, cleans and thrusters were initially rehearsed using body weight, a PVC pipe or an empty barbell. Participants subsequently performed two or three sets of six to eight repetitions with approximately 30–40% of their estimated one-repetition maximum. Pull-ups, push-ups and other gymnastic movements were practised using standard or scaled variations according to individual ability.

Exercise scaling included the use of resistance bands for pull-ups, elevated supports for push-ups, reduced ranges of motion and lighter external loads. Loads were increased only when participants demonstrated adequate postural alignment, movement control and the ability to complete all prescribed repetitions without substantial technical deterioration. This progression was intended to support movement quality and reduce the risk associated with complex exercises performed at high intensity (Behm et al., 2016).

Workout of the Day

The WOD represented the main conditioning component of the session and lasted between 12 and 15 minutes. Each

workout included three to five exercises selected from the following categories:

- resistance and weightlifting exercises, including deadlifts, squats, cleans and thrusters;
- gymnastic and body-weight exercises, including pull-ups, push-ups and burpees;
- metabolic-conditioning activities, including running, rowing and jumping rope.

The workouts were organised using AMRAP, EMOM and For Time formats. AMRAP workouts required participants to complete as many technically correct rounds or repetitions as possible within a predetermined time. During EMOM workouts, participants completed a prescribed number of repetitions at the beginning of each minute and used the remaining time for recovery. For Time workouts required participants to complete a predetermined volume of work in the shortest possible time while maintaining appropriate movement technique.

Each WOD generally included 6–15 repetitions per resistance or gymnastic exercise, running or rowing distances of 200–400 metres and sets of 30–60 jump-rope repetitions. Resistance exercises were performed using loads corresponding to approximately 40–65% of the participant's estimated 1RM. Maximum or near-maximum loads were not used during the WOD.

Recovery depended on the workout format. During EMOM sessions, the time remaining within each minute served as recovery. During AMRAP and For Time sessions, participants were allowed brief self-selected pauses of approximately 10–30 seconds when they could no longer maintain the prescribed technique or exercise intensity.

Training intensity was monitored using the 0–10 rating of perceived exertion scale. Participants were asked to maintain an RPE between 7 and 9 during the main workout. Session RPE was recorded approximately 15 minutes after the end of each session. The instructors reduced the load, number of repetitions or movement complexity when the participant's technique deteriorated or the perceived exertion exceeded the intended level.

The combination of functional resistance exercises, gymnastic movements and metabolic-conditioning activities was intended to stimulate cardiovascular and metabolic adaptations through repeated alternation between high-intensity work and incomplete recovery (Claudino et al., 2018). High-intensity exercise may also influence metabolic regulation and physiological processes involved in energy balance (Di Maio et al., 2026).

Progression of the CrossFit programme

The programme followed a progressive structure across the 12 weeks. Since the participants already had at least four years of CrossFit experience, the first phase was used for technical standardisation rather than initial familiarisation.

During weeks 1–4, emphasis was placed on movement standards, pacing and technical control. During weeks 5–8, total repetitions, external loads or WOD duration were progressively increased by approximately 5–10%, depending on individual tolerance. During weeks 9–12, progression was primarily achieved by increasing work density, reducing self-selected recovery periods and using more complex combinations of exercises.

Table 1. Summary of the Training Protocol for the Experimental Group

Intervention phase	Weeks	WOD duration	Resistance load	Target RPE	Principal objective
Technical standardisation	1–4	10–12 min	40–50% 1RM	7–8	Standardisation of movement technique and moderate work density
Progressive overload	5–8	12–14 min	45–60% 1RM	7–8	Increased training volume, repetitions and exercise density
Higher-density conditioning	9–12	12–15 min	50–65% 1RM	8–9	Maintenance of technique under greater metabolic demand

Only one principal training variable—load, volume, duration or recovery—was increased within the same session. When participants were unable to maintain correct technique, the external load was reduced by approximately 10–20%, the repetitions were decreased or a scaled exercise variation was used.

CrossFit cool-down

The session concluded with approximately three minutes of low-intensity walking or cycling and controlled breathing, followed by seven minutes of static and dynamic stretching. Stretching exercises targeted the quadriceps, hamstrings, gluteal muscles, calf muscles, pectoral muscles, shoulders and lower back.

Each static stretch was maintained for approximately 20–30 seconds and repeated twice without reaching a painful range of motion. The cool-down was intended to promote a gradual reduction in cardiovascular demand and relieve muscular tension accumulated during the workout (Herbert & Gabriel, 2002).

Traditional resistance-training programme

The control group completed a traditional resistance-training programme with the same intervention duration, weekly frequency and session duration as the CrossFit group. Participants attended two supervised 60-minute sessions per week for 12 weeks, corresponding to a maximum of 24 sessions.

The programme focused on muscular strength and hypertrophy and did not include metabolic-conditioning circuits, continuous aerobic exercise or high-intensity interval training. This distinction was maintained throughout the study to preserve the methodological contrast between traditional resistance training and high-intensity functional training (Feito et al., 2018).

Each session consisted of:

- a 10-minute general warm-up;
- 40–45 minutes of traditional resistance training;
- 5–10 minutes of cool-down and stretching.

General warm-up

The warm-up included dynamic joint mobility and low-intensity muscle-activation exercises targeting the muscle groups involved in the subsequent resistance-training session. Participants performed body-weight squats, dynamic lunges, shoulder rotations and trunk-stability exercises.

Before each principal multi-joint exercise, participants completed two preparatory sets: the first set at approximately

40% of the working load for 10 repetitions and the second set at approximately 60% of the working load for six repetitions. These preparatory sets were not included in the prescribed training volume.

Resistance-training component

The programme included the squat, leg press, bench press, seated or bent-over rowing and shoulder press. Supplementary exercises for the elbow flexors, elbow extensors, hamstrings, calf muscles and abdominal muscles were included when time permitted.

The two weekly sessions followed a full-body structure. The exercises involving the largest muscle groups and the most technically demanding multi-joint movements were performed at the beginning of each session.

Participants completed three sets of 8–12 repetitions for each principal exercise. Initial loads corresponded to approximately 65% of estimated 1RM and were progressively increased to approximately 75% of 1RM during the final four weeks. Recovery intervals were two minutes for squats, leg presses, bench presses and rowing exercises and approximately 90 seconds for shoulder presses and supplementary exercises.

Repetitions were performed using a controlled tempo consisting of approximately two seconds during the eccentric phase and one to two seconds during the concentric phase. Participants were instructed to complete the prescribed range of motion without using momentum or substantially altering their posture.

The estimated 1RM was determined during the week preceding the intervention using a submaximal five-repetition maximum assessment. The load was adjusted on the basis of the heaviest load that could be completed for five technically correct repetitions.

The resistance-training progression was organised as follows:

Table 2. Summary of the Training Protocol for the Control Group

Intervention phase	Weeks	Sets × repetitions	Approximate load	Recovery
Initial phase	1–4	3 × 12	65% 1RM	90–120 s
Intermediate phase	5–8	3 × 10	70% 1RM	90–150 s
Final phase	9–12	3 × 8	75% 1RM	120–180 s

When a participant completed the maximum number of prescribed repetitions in all three sets with correct technique during two consecutive sessions, the external load was increased by approximately 2.5% for upper-body

exercises and 5% for lower-body exercises. When the participant could not complete the minimum number of prescribed repetitions, the load was maintained or reduced by approximately 5% in the subsequent session.

Unlike the CrossFit programme, exercises were performed in conventional sets and were not organised as circuits. Resistance exercises were not alternated with running, rowing, jumping rope or other activities intended to maintain elevated cardiorespiratory demand.

Resistance-training cool-down

The control-group sessions concluded with approximately two minutes of low-intensity walking and five to eight minutes of static stretching targeting the muscle groups involved in the resistance exercises. Each stretch was maintained for 20–30 seconds and repeated once or twice. No cardiovascular-conditioning or metabolic-training activity was included during the cool-down.

Cardiopulmonary exercise testing (CPET)

The cardiopulmonary exercise test (CPET) was used to assess the participants' aerobic capacity and was administered at two distinct points in time: at T0 before the training intervention began and at T1 after the 12-week programme had finished. The test was performed under standardised conditions to ensure the reliability and comparability of the measurements taken before and after the intervention, in accordance with international recommendations for conducting CPET (Balady et al., 2010).

During the CPET, participants were instructed to maintain a consistent speed or cadence throughout the test and to refrain from using self-regulation strategies to adjust the intensity, following the operator's guidance. In the case of the treadmill test, the protocol involved gradually and progressively increasing the speed and/or incline at regular intervals to induce a continuous and increasing workload. Participants had to maintain the pace set by the protocol until they could no longer sustain the required effort, as in classic incremental protocols for assessing aerobic capacity (Wasserman et al., 1987).

For the cycle ergometer test, participants were asked to maintain a constant pedalling cadence of between 60 and 80 revolutions per minute while the workload increased progressively in increments of power expressed in watts at set intervals.

In accordance with the guidelines for performing incremental tests on a cycle ergometer (Balady et al., 2010; Forman et al., 2010), the athletes were encouraged to maintain the prescribed cadence for as long as possible until they reached voluntary exhaustion.

Throughout the test, participants received standardised verbal instructions to encourage them to continue exercising and to ensure they made maximum effort. However, they were not given any feedback on the physiological values recorded. Participants were asked to report any symptoms of excessive fatigue, severe breathlessness, dizziness or pain, as these would have led to the test being terminated immediately for safety reasons, in accordance with the safety guidelines for exercise testing.

Gradually increasing the intensity while maintaining a set speed, incline or cadence allowed for a precise examination

of the cardiorespiratory response to the increased workload, enabling the accurate identification of maximum aerobic capacity and personal physiological thresholds (Beaver et al., 1986).

Results

Quantitative Data Analysis

A quantitative analysis was conducted to examine changes in the principal cardiopulmonary outcomes from baseline (T0) to post-intervention (T1) and to compare the effects of the CrossFit and traditional resistance-training programmes. Descriptive data are reported as means and standard deviations. The normality of the distributions was assessed using the Shapiro–Wilk test and through the visual inspection of histograms and Q–Q plots, while the homogeneity of variances was examined using Levene's test. No substantial violations of the assumptions required for parametric analyses were identified.

Baseline comparability was assessed using independent-samples t-tests for continuous variables. Changes in each physiological outcome were analysed using a two-way mixed-design analysis of variance, with time (T0 vs T1) as the within-subject factor and training group (CrossFit vs traditional resistance training) as the between-subject factor. The group-by-time interaction represented the principal test of intervention effectiveness.

When a statistically significant interaction was identified, Bonferroni-adjusted paired-samples t-tests were performed to examine within-group changes. Individual change scores were also compared between groups using independent-samples t-tests. Partial eta squared (η^2p) was reported as the effect-size measure for group-by-time interactions. Cohen's d was calculated for within-group changes, whereas Cohen's d , based on the pooled standard deviation of the change scores, was calculated for between-group differences. Effect sizes were interpreted as small, moderate or large using conventional thresholds. Statistical significance was set at $p < .05$, and 95% confidence intervals were reported where appropriate.

The individual percentage change was calculated using the following formula:

$$\Delta\% = [(T1 - T0) / T0] \times 100.$$

All 80 participants completed both the baseline and post-intervention assessments. Therefore, no missing outcome data were recorded, and all participants were included in the quantitative analysis.

Baseline comparability

At baseline, no statistically significant differences were observed between the CrossFit and traditional resistance-training groups in any of the principal physiological outcomes. Mean $\text{VO}_{2\text{max}}$ was $43.9 \pm 5.4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in the CrossFit group and $44.1 \pm 5.2 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in the control group, with a mean difference of $-0.20 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (95% CI $[-2.56, 2.16]$, $p = .866$, $d = -0.04$).

Ventilatory threshold was $68.8 \pm 4.9\%$ of $\text{VO}_{2\text{max}}$ in the CrossFit group and $69.1 \pm 5.0\%$ in the control group. The mean difference was -0.30 percentage points (95% CI $[-2.50, 1.90]$, $p = .787$, $d = -0.06$).

Table 3. Baseline comparability of the principal physiological outcomes

Outcome	CrossFit group, T0 (n = 40)	Control group, T0 (n = 40)	Mean difference (95% CI)	p	Cohen's d
VO ₂ max, mL·kg ⁻¹ ·min ⁻¹	43.9 ± 5.4	44.1 ± 5.2	-0.20 (-2.56 to 2.16)	.866	-0.04
Ventilatory threshold, % VO ₂ max	68.8 ± 4.9	69.1 ± 5.0	-0.30 (-2.50 to 1.90)	.787	-0.06
Heart rate at the same submaximal workload, beats·min ⁻¹	151.4 ± 9.5	150.8 ± 9.7	0.60 (-3.67 to 4.87)	.781	0.06

Heart rate at the same standardised submaximal workload was 151.4 ± 9.5 beats·min⁻¹ in the CrossFit group and 150.8 ± 9.7 beats·min⁻¹ in the control group. The mean difference was 0.60 beats·min⁻¹ (95% CI [-3.67, 4.87], $p = .781$, $d = 0.06$). These results demonstrated adequate baseline comparability between the two groups.

Changes in maximal oxygen uptake

Following the 12-week intervention, VO₂max in the CrossFit group increased from 43.9 ± 5.4 to 47.5 ± 5.6 mL·kg⁻¹·min⁻¹. The mean increase was 3.60 mL·kg⁻¹·min⁻¹ (95% CI [2.96, 4.24]), corresponding to an improvement of 8.2%. The within-group change was statistically significant and associated with a large effect size ($p < .001$, $dz = 1.80$).

The traditional resistance-training group showed a smaller increase in VO₂max, from 44.1 ± 5.2 to 44.9 ± 5.3 mL·kg⁻¹·min⁻¹. The mean change was 0.84 mL·kg⁻¹·min⁻¹ (95% CI [0.33, 1.35]), corresponding to an improvement of 1.9%. The change remained statistically significant following Bonferroni correction, although the effect size was moderate ($p = .004$, $dz = 0.53$).

Changes in ventilatory threshold

Ventilatory threshold in the CrossFit group increased from 68.8 ± 4.9% to 73.2 ± 4.8% of VO₂max. The mean increase was 4.40 percentage points (95% CI [3.47, 5.33]), corresponding to a relative improvement of 6.4%. The change was statistically significant and associated with a large within-group effect ($p < .001$, $dz = 1.52$).

In the control group, ventilatory threshold increased from 69.1 ± 5.0% to 69.9 ± 5.0% of VO₂max. The mean increase was 0.76 percentage points (95% CI [-0.14, 1.66]), corresponding to a relative improvement of 1.1%. This change was not statistically significant after Bonferroni correction and was associated with a small effect size ($p = .188$, $dz = 0.27$).

Changes in submaximal heart rate

Heart rate at the same standardised submaximal workload decreased in the CrossFit group from 151.4 ± 9.5 to 145.8 ± 9.2 beats·min⁻¹. The mean reduction was 5.60 beats·min⁻¹ (95% CI [-6.88, -4.32]), corresponding to a decrease of 3.7%. The reduction was statistically significant and associated with a large within-group effect ($p < .001$, $dz = -1.40$).

In the control group, heart rate decreased from 150.8 ± 9.7 to 149.4 ± 9.6 beats·min⁻¹. The mean reduction was 1.36 beats·min⁻¹ (95% CI [-2.90, 0.18]), corresponding to a decrease of 0.9%. This change was not statistically significant and was associated with a small effect size ($p = .162$, $dz = -0.28$).

Group-by-time interactions

The mixed-design analyses of variance identified statistically significant group-by-time interactions for all three principal physiological outcomes, indicating that the magnitude of change differed significantly between the two training conditions.

Table 4. Baseline, post-intervention and within-group changes in the principal physiological outcomes

Outcome and group	T0, mean ± SD	T1, mean ± SD	Mean change (95% CI)	Change, %	Adjusted p	Cohen's dz
VO ₂ max, mL·kg ⁻¹ ·min ⁻¹						
CrossFit	43.9 ± 5.4	47.5 ± 5.6	3.60 (2.96 to 4.24)	+8.2	< .001	1.80
Control	44.1 ± 5.2	44.9 ± 5.3	0.84 (0.33 to 1.35)	+1.9	.004	0.53
Ventilatory threshold, % VO ₂ max						
CrossFit	68.8 ± 4.9	73.2 ± 4.8	4.40 (3.47 to 5.33)	+6.4	< .001	1.52
Control	69.1 ± 5.0	69.9 ± 5.0	0.76 (-0.14 to 1.66)	+1.1	.188	0.27
Heart rate at the same submaximal workload, beats·min ⁻¹						
CrossFit	151.4 ± 9.5	145.8 ± 9.2	-5.60 (-6.88 to -4.32)	-3.7	< .001	-1.40
Control	150.8 ± 9.7	149.4 ± 9.6	-1.36 (-2.90 to 0.18)	-0.9	.162	-0.28

Note. Data are presented as mean ± standard deviation. T0 = baseline assessment; T1 = assessment after the 12-week intervention; CI = confidence interval; SD = standard deviation; VO₂max = maximal oxygen uptake. Within-group comparisons were performed using paired-samples t-tests. Reported p-values were adjusted using the Bonferroni procedure. A negative change in heart rate indicates improved cardiovascular efficiency at the same external workload.

Table 5. Group-by-time interactions and between-group differences in change

Outcome	CrossFit change, mean $\pm$ SD	Control change, mean $\pm$ SD	Difference in change (95% CI)	$F_{(1,78)}$	p	η^2p	Cohen's d
VO ₂ max, mL.kg ⁻¹ .min ⁻¹	3.60 $\pm$ 2.00	0.84 $\pm$ 1.60	2.76 (1.95 to 3.57)	46.45	< .001	.373	1.52
Ventilatory threshold, % VO ₂ max	4.40 $\pm$ 2.90	0.76 $\pm$ 2.80	3.64 (2.37 to 4.91)	32.61	< .001	.295	1.28
Heart rate at the same submaximal workload, beats.min ⁻¹	-5.60 $\pm$ 4.00	-1.36 $\pm$ 4.80	-4.24 (-6.21 to -2.27)	18.42	< .001	.191	-0.96

For VO₂max, the group-by-time interaction was statistically significant, $F_{(1,78)} = 46.45$, $p < .001$, $\eta^2p = .373$. The mean improvement in the CrossFit group was 2.76 mL.kg⁻¹.min⁻¹ greater than that observed in the control group (95% CI [1.95, 3.57]). The between-group effect size was large ($d = 1.52$).

A statistically significant interaction was also identified for ventilatory threshold, $F_{(1,78)} = 32.61$, $p < .001$, $\eta^2p = .295$. The improvement in the CrossFit group exceeded that observed in the control group by 3.64 percentage points (95% CI [2.37, 4.91]), with a large between-group effect size ($d = 1.28$).

For heart rate at the same standardised submaximal workload, the group-by-time interaction was statistically significant, $F_{(1,78)} = 18.42$, $p < .001$, $\eta^2p = .191$. The reduction in heart rate was 4.24 beats.min⁻¹ greater in the CrossFit group than in the control group (95% CI [-6.21, -2.27]), with a large between-group effect size ($d = -0.96$).

Overall, the statistically significant group-by-time interactions indicated that the CrossFit and traditional resistance-training groups followed different physiological trajectories during the 12-week intervention. The CrossFit programme produced greater improvements in maximal aerobic capacity, ventilatory threshold and cardiovascular efficiency during submaximal exercise. Although the control group demonstrated a small-to-moderate improvement in VO₂max, only the CrossFit group achieved statistically significant and large improvements across all three principal physiological outcomes. These findings support the interpretation that the repeated combination of functional resistance exercises, gymnastic movements and metabolic-conditioning activities elicited cardiorespiratory adaptations that were not reproduced to the same extent by traditional resistance training alone.

Qualitative data analysis

The qualitative analysis of the semi-structured interviews allowed us to explore the athletes' individual experiences regarding the effects of training on aerobic endurance, perception of effort, and overall bodily experience during physical activity. Thematic analysis of the transcripts revealed recurring interpretative categories, reflecting perceived changes not only on a physiological level, but also on a cognitive, emotional, and functional level, outlining a detailed picture of the athletes' experience over the 12 weeks of the intervention.

In the experimental group (CrossFit), most participants reported a clear sense of progress in managing fatigue, describing a perception of greater 'control' over effort during training. The athletes reported perceiving fatigue as less sudden and less limiting than in the pre-intervention phase,

emphasizing a greater ability to distribute energy throughout the workout. In particular, many pointed out that during WODs characterized by high work density or prolonged duration, it was possible to maintain a more constant pace, reducing the need for frequent or prolonged breaks.

A frequently reported aspect concerned the improvement in respiratory perception. Several athletes described their breathing as more "controlled" and "efficient," associated with less breathlessness in the middle and final stages of training. This change was interpreted by the participants themselves as a greater ability to adapt to the required intensity, with a reduction in anxiety related to breathing difficulties and greater confidence in sustaining high levels of effort.

A second central theme concerned tolerance to submaximal effort, with many athletes reporting a perceived shift in the threshold beyond which fatigue became excessive. In particular, metabolic conditioning exercises (such as running, rowing, or combined workouts) were described as more "manageable," both in terms of continuity of execution and in terms of recovery between the various phases of the workout. Athletes often reported being able to resume activity more quickly after short breaks, suggesting a perceived improvement in recovery capacity during exercise.

Another element that emerged concerned the transfer of improvements to everyday life, an aspect that played a significant role in the narratives of the CrossFit group participants. Many athletes reported greater ease in performing daily activities that require moderate physical effort, such as walking at a brisk pace, climbing several flights of stairs without stopping, or carrying loads for prolonged periods. These changes were often associated with a general feeling of greater physical efficiency, reduced fatigue, and improved overall physical well-being.

In the control group (weight training), the athletes' opinions highlighted a different experience. Although many participants reported perceived improvements in muscle strength, joint stability, and confidence in performing movements with overload, perceptions of aerobic endurance were more limited. In particular, most athletes did not report significant changes in fatigue management during prolonged or high cardiovascular demand activities, nor did they report a noticeable improvement in their ability to sustain continuous effort.

Some participants in the control group also pointed out that, although they felt stronger, the feeling of breathlessness or fatigue during aerobic activities or in daily life remained substantially unchanged compared to the pre-intervention period, suggesting a perception of predominantly muscular rather than cardiorespiratory adaptations.

Overall, the integration of qualitative results with quantitative data showed a strong convergence between

objectively measured improvements and subjectively perceived changes, particularly in the CrossFit group. This convergence reinforces the interpretation of the results, suggesting that the cardiorespiratory adaptations detected through CPET are clearly reflected in the athletes' experience, contributing to a more complete, ecological, and contextualized understanding of the effects of training on aerobic endurance.

Discussion

The results obtained indicate that CrossFit's integrated, high-intensity approach could promote more significant cardiorespiratory adaptations than a program focused solely on weight lifting. In particular, the joint improvement of indicators related to aerobic performance and sustainability of effort appears consistent with the principle of specific training, according to which physiological adaptations are strongly influenced by the characteristics of the training stimulus. Repeated exposure to tasks that alternate between moments of high metabolic demand and partial recovery seems, in fact, to be able to stimulate various energy systems simultaneously (Jacob et al., 2020), promoting both "central" adaptations, such as increased cardiovascular system efficiency, and "peripheral" adaptations, linked to better oxygen utilization at the muscular level, such as increased mitochondrial density and oxidative capacity (Bassett & Howley, 2000; MacInnis & Gibala, 2017). These adaptations are reflected in a greater ability to sustain prolonged or repeated workloads, even at submaximal intensities, which is particularly relevant in disciplines characterized by intermittent and variable efforts such as CrossFit (Claudino et al., 2018).

From this perspective, CrossFit seems to act not only on maximal aerobic capacity but also on the quality of performance during prolonged exercise, improving exercise tolerance and intensity management over time. This result coincides with findings from previous research on high-intensity functional training, which reported improvements not only in $\text{VO}_{2\text{max}}$ but also in the ability to manage high workloads with less perceived fatigue (Feito et al., 2018; Heinrich et al., 2014). This aspect takes on significant functional value, as the ability to maintain high intensity without a rapid decline in performance is a key factor in both athletic performance and efficiency in daily activities that require continuous or repeated effort.

Another element of particular interest that emerged from the study concerns the convergence between objective measures and subjective perceptions. The consistency observed between the changes detected through CPET and the experiences reported by the athletes reinforces the ecological interpretation of the results, suggesting that physiological adaptations are not confined to the laboratory setting but translate into perceptible and functionally significant changes during training and in daily life (Wasserman et al., 1987).

The consistency observed between the changes detected through CPET and the experiences reported by the athletes highlights the broader impact of structured sport interventions, suggesting that physiological adaptations may extend beyond performance outcomes and contribute to meaningful changes in participation, well-being, and daily

life experiences (Di Palma et al., 2025). The perception of improved fatigue management, more effective respiratory control, and greater continuity of action is a central element of the athletes' experience and can be considered an indirect indicator of the effectiveness of the intervention, in line with approaches that integrate physiological outcomes and subjective experience in the evaluation of training (Creswell & Plano Clark, 2010).

This alignment of quantitative and qualitative data is particularly relevant from motivational and behavioural perspectives. Perceiving greater control over effort and reduced fatigue can positively influence adherence to the training programme, the willingness to sustain high loads and the quality of commitment during sessions. All of these factors are considered crucial for maintaining the long-term benefits of physical exercise (Gipson et al., 2021). In this sense, the benefits of physical exercise could extend beyond immediate physiological improvements, fostering inclusive participation and contributing to the stimulation of cognitive capacities, particularly attentional processes (Tafari et al., 2025), in line with recent mixed-methods research showing that structured sport interventions produce not only measurable performance improvements but also significant motivational, relational and reflective benefits perceived by participants, while supporting the maintenance of a physically active lifestyle and a greater awareness of one's physical abilities over time. From this perspective, physical activity can also be effectively integrated into the school context as a pedagogical tool aimed at promoting inclusion, well-being, and students' cognitive development (Latino, et al., 2025).

Conclusion

When interpreting the results, it is important to consider certain methodological aspects that may have influenced the magnitude of the observed effects and how generalisable they are. Firstly, assigning participants to groups based on their usual training type (CrossFit vs. weightlifting) creates a quasi-experimental design, which reduces the ability to attribute differences exclusively to the intervention with causal certainty. This is because pre-existing factors, such as motivation, lifestyle, individual preferences and initial fitness level, may have contributed to the changes. Furthermore, although CPET is a highly reliable method, using two different ergometers (treadmill or cycle ergometer) may introduce variability related to movement specificity and familiarity with the testing procedure. To reduce this effect, future studies should standardise the ergometer for all participants or stratify the analysis by test type. Another limitation is the difficulty of controlling external factors such as diet, sleep quality, extra-protocol physical activity and recovery management, which are not always fully monitorable in 'real' contexts such as a sports association and which may affect both physiological adaptation and subjective perceptions. From a qualitative point of view, collecting interviews at the end of the intervention may have favoured a retrospective reading influenced by social desirability or expectations of improvement. In future, integrating weekly diaries or short longitudinal check-ins would provide a more accurate understanding of how experiences evolve over time.

In light of these considerations, future prospects could involve more controlled experimental designs (e.g.

randomised) and the systematic monitoring of internal and external load (e.g. heart rate, RPE, total volume and work density), in order to more accurately describe the actual training 'dose' received. Expanding the outcomes beyond cardiorespiratory markers to include recovery and adaptation variables (e.g. body composition, neuromuscular markers, performance in specific tests and stress/fatigue indicators) would also be useful, as would conducting more refined threshold analyses (determination methods and reliability). Finally, multicentre studies involving more heterogeneous samples in terms of gender, level of experience and age groups could clarify whether the observed effectiveness is comparable in different populations, and which training components (metcon, intervals, density and choice of movements) are most decisive in producing improvements (VanBuskirk, 2026). This would help to build more targeted and transferable protocols in sports and health promotion contexts.

Ethics Approval

The study was approved by the Ethics Committee of the University of Naples Parthenope (DiSMMeB, Prot. No. 16761/2026). Written informed consent was obtained from all participants and/or their legal guardians prior to participation in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Фізіологічні реакції на тренування з кросфіту: оцінка аеробної витривалості за допомогою кардіопульмонального навантажувального тестування

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

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Обґрунтування. Кросфіт — це метод високоінтенсивного тренування, що включає різноманітні функціональні рухи та є потенційно ефективним для покращення аеробної витривалості.

Мета дослідження. У цьому дослідженні застосовано підхід змішаних методів для оцінки впливу структурованої програми з кросфіту на кардіореспіраторну підготовленість шляхом поєднання об'єктивних вимірювань із суб'єктивним сприйняттям спортсменів.

Матеріали та методи. Загалом 80 осіб, які регулярно тренуються (віком 20–35 років), були розділені на експериментальну групу (кросфіт) та контрольну групу (силові тренування). Кількісну оцінку проводили за допомогою кардіопульмонального навантажувального тестування (КПНТ) у двох часових точках (T0 та T1 — через 12 тижнів), аналізуючи максимальне споживання кисню (VO₂ max), вентиляційний поріг та реакцію частоти серцевих скорочень на субмаксимальні

навантаження. Паралельно наприкінці інтервенції було проведено напівструктуровані інтерв'ю, дані яких проаналізували за допомогою тематичного аналізу.

Результати. Результати продемонстрували вищі показники покращення в групі занять з кросфіту порівняно з контрольною групою: середнє збільшення $\text{VO}_2 \text{ max}$ становило +8.2% проти +1.9%, підвищення вентиляційного порогу — +6.4% проти +1.1%, а зниження частоти серцевих скорочень за однакового навантаження становило –3.7% проти –0.9% відповідно.

Висновки. Результати інтерв'ю підтвердили поліпшення контролю втоми, вищу ефективність дихання та перенесення позитивних ефектів тренувань на повсякденну діяльність. Таким чином, отримані дані свідчать про те, що 12-тижнева програма з кросфіту стимулює значні кардіореспіраторні адаптації, що узгоджуються із суб'єктивним сприйняттям спортсменів.

Ключові слова: кросфіт, aerobic витривалість, $\text{VO}_2 \text{ max}$, кардіопульмональне навантажувальне тестування, високоінтенсивне тренування.

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