Article

Time course of recovery following CrossFit® Karen Benchmark Workout in trained men

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Abstract: The study describes the acute and delayed time course of recovery following the CrossFit® Benchmark Workout Karen. Eight trained men (28.4±6.4 years; 1RM back squat 139.1±26.0 kg) undertook the Karen protocol. The protocol consists of 150 Wall Balls, aiming to hit a target 3 meters high. Countermovement jump height (CMJ), creatine kinase (CK), and perceived recovery status scale (PRS) (general, lower and upper limbs) were assessed pre, post-0h, 24h, 48h and 72h after the session. The CK concentration 24h after was higher than pre-exercise (338.4 U/L vs. 143.3 U/L; effect size: 0.74; $p \leq 0.05$). At 48h and 72h following exercise, CK concentration had returned to baseline levels. The PRS general and of the lower limbs were lower in the 24-hours post-exercise compared to pre-exercise (PRS general: 4.7 ±1.5 and 7.9 ±1.7 mmol/L; and PRS of the lower limbs: 4.0 ±2.5 and 7.9 ±0.8, respectively). The PRS general, lower, and upper limbs were reduced at 48-post exercise compared to 72-hours post-exercise scores. Our findings provide insights into the fatigue profile and recovery in acute CrossFit® and can be useful to coaches effectively design the daily session.

Keywords: Functional Fitness; High intensity Functional training; Periodization; Overreaching; Muscle recovery

1. Introduction

CrossFit® training program is characterized by utilizing high training volume and using large exercise types in high intensity [1]. In the end of 2000 decade, these kinds of programs spread in the world, growing the number of practitioners and popularity [2]. Through the innumerous benefits described before [3], CrossFit® seems to be secure and effective when coaches precisely control different important tools to measure properly intensity and stress levels [4,5].

The training session contemplates the development of multiple physical abilities, starting with the weightlifting exercises (clean & jerk, snatch, and its variations), powerlifting exercises (bench press, overhead press, front, and back squat) and lastly the metabolic conditioning [6,7]. A recently systematic review considered that CrossFit® training session normally causes a substantial metabolic stress, leading to metabolite accumulation (e.g., lactate up to 18 mmol/L) and increased markers of muscle damage (interleukin-6 - IL-6, and creatine kinase – CK, up to 24h post- exercise) [8]. High levels of muscular fatigue, assessed via changes in countermovement jump performance, are also seen immediately after the sessions, with the effects lasting up to 48 hours, depending on the characteristics of the session performed [9,10].

The greater metabolic stress induced in a CrossFit® session may lead to exercise-induced muscle damage (EIMD), particularly when a high volume of repetitions is performed, with EIMD being even greater if the participants are unaccustomed to the exercises performed [11]. When comparing the perceptual responses and post-exercise physical disfunction between a CrossFit® session and a session based on the guidelines of the American College of Sports Medicine, Drum et al. [12] found significant differences between sessions. CrossFit® participants reported a higher rating of perceived exertion (RPE) and a greater perceived number of hard training days per week. Feelings of excessive fatigue, muscle soreness, muscle swelling, shortness of breath, muscle pain to light touch, and limited movement in muscles used during exercise within 48-hours post-exercise were also higher in CrossFit® participants. These responses following CrossFit® sessions highlight the importance of understanding the time-course of recovery following sessions to minimize the risk of maladaptation due to insufficient recovery between sessions and optimize training prescription.

Recovery is a multi-faceted restorative process relative to time, considering the individual's physiological and psychological responses to a stimulus [13]. Due to the multifactorial nature of recovery, the assessment of the recovery–fatigue continuum should be relative to the demands of the sport [13]. While performance measures represent the most sport-specific outcomes, other physiological and psychological measures provide integral information on an athlete's recovery and biophysical balance [13]. Stress markers such as creatine kinase (CK,) counter movement jump (CMJ) and recovery status (PRS) remain largely unknown in CrossFit® training programs, despite their potential to identify athletes' recovery status following exhaustive sessions[7].

Despite the importance of performance and physiological markers, the perception of an athlete's readiness to perform describes a critical determinant of recovery. In this context, Laurent et al. [14] proposed a perceived recovery status scale (PRS), which is similar but opposite to a perceived exertion scale (RPE) (10–12). Both scales are based on the subjective physical and mental feelings of the athlete. However, while the rating of perceived exertion (RPE) is utilized during or after a session, the PRS scale is utilized prior to the session to identify the athletes' recovery status. The PRS scale has been shown to be a reliable tool to assess the perceived recovery state of individuals, demonstrating accuracy (> 80%) in identifying changes in performance when the individuals reported feelings of being under-recovered [14]. A practical method of assessing athletes' recovery status prior to a session might allow coaches and practitioners to adjust the training session to match the individuals' perceived recovery status, optimizing training outcomes [14,15].

Furthermore, previous resistance training studies utilizing protocols to the point of muscle failure [16] or with a high-volume of training [17,18] have demonstrated an impairment in performance in the subsequent session. However, the acute responses to a high-volume and fatiguing CrossFit® session, particularly in relation to changes in performance, exercise-induced muscle damage, and perceived recovery status have yet to be investigated. Understanding the time-course of recovery following the strenuous sessions can provide coaches and practitioners with important information to optimize training programs. This is particularly important in CrossFit®, since many sessions require a near-maximal or maximal effort from the participants.

Therefore, the purpose of this study to describe the acute and delayed time course of recovery following the CrossFit® benchmark workout Karen, in healthy trained subjects. Based on the current evidence, it was hypothesized that the participants would experience a significant increase in CK that would be mirrored by changes in CMJ and the participant's perceived recovery status.

2. Materials and Methods

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2.1. Participants

Eight male subjects (age 28.4±6.4 years old; 1RM back squat: 139.1±26.0 kg) were recruited. All participants were free of injury and known illness, were not using drugs to enhance performance, and had a minimum experience of six months with CrossFit®. Indirect maximal aerobic capacity (VO_2 max) and strength (1RM) are described in table 1, and were assessed two weeks before the protocol. Participants were advised to refrain from ingesting alcohol for 24 h before all tests, avoid any exercise 48h before and 72h after the protocol, and to maintain their normal daily diet during the study. All participants signed an informed consent document, and the study was approved by the University Research Ethics Committee for Human Use (2.698.225; 7 June 2018) and conformed to the

2.2. Protocol

This study was designed to analyze the time-course effects of the CrossFit® benchmark workout Karen on the physiological, psychological and performance responses in trained adult men. The protocol consists of 150 repetitions of Wall Balls, with athletes aiming to hit a target 3 meters high, using a 9 kg medicine ball. In this study, the benchmark Karen was the independent variable, while the dependent variables consisted of changes in creatine kinase, countermovement jump and perceived recovery status scale (PRS) (general, lower, and upper limbs) (Figure 1).

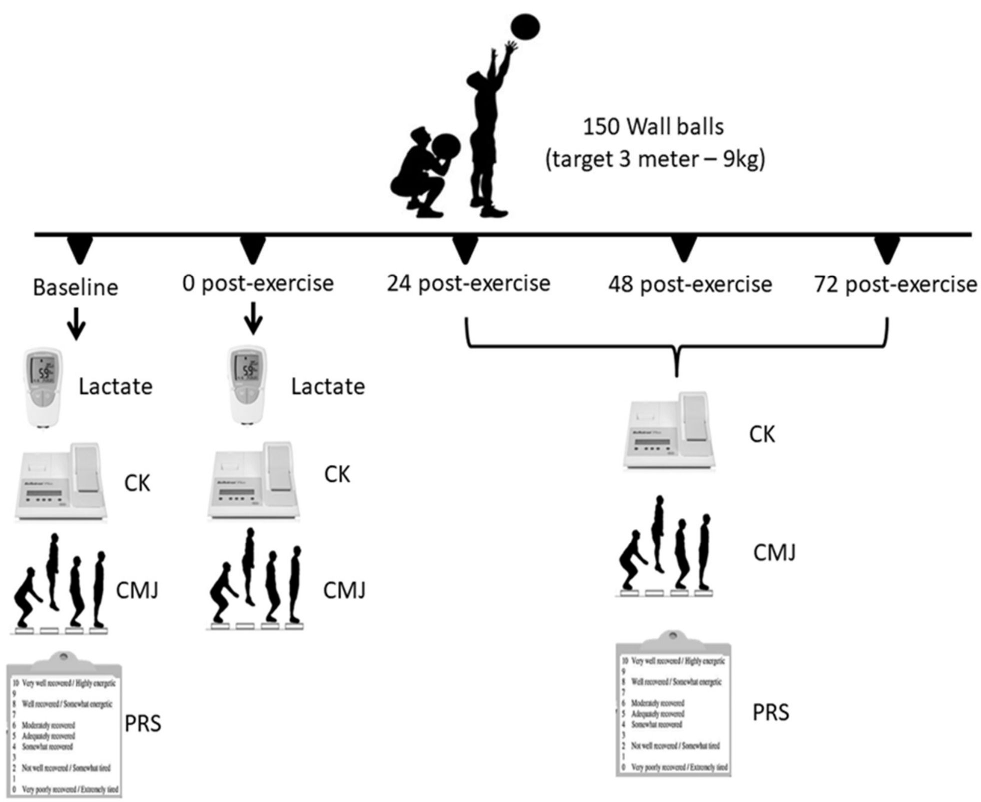

Figure 1. Schematic study design and timeline used to examine the time-course effects of Creatine kinase, height of counter movement jump and perceived recovery scale.

2.3. Karen Protocol

The CrossFit® WOD Karen corresponds to a timed training of one element (medicine ball throws; 9.07 kg for a height of 3 meters), which consists of completing a task of 150 throws of medicine ball to wall in the shortest time possible, therefore, a higher performance in this WOD corresponds to a shorter time to do it.

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2.4. Creatine kinase and blood Lactate analysis

Whole-blood creatine kinase activity was assessed from a single fingertip capillary sample with the subject in a seated position. After pre-warming the hand, a sample of blood (30 μL) was obtained and analyzed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany)[7]. Before each test session, quality control (calibration) measurements were undertaken according to the manufacturer's recommendations. The ''normal'' reference range for creatine kinase activity, as provided by the manufacturer, is 24–195 U/L.

The blood lactate collection, management, and analysis were determined according to Falk Neto et al.[19]. Capillary blood samples were collected through a transcutaneous puncture on the medial side of the tip of the middle finger using a disposable hypodermic lancet. Blood lactate concentration was determined by photometric reflectance on a validated Portable Accutrend Plus system (Roche, Sao Paulo, Brazil).

2.5. Perceived Recovery Scale (PRS)

Immediately before the training sessions, the athletes were asked to rate their perceived recovery status according to the PRS Scale. The scale (Figure 2) ranges from 0 to 10, with a score of "0" indicating that the athlete is "very poorly recovered / extremely tired" and a score of "10" indicates that the athlete is "very well recovered / highly energetic". A score of 0, 1, or 2, is associated with an expected reduction in performance, while a score of 8, 9, or 10, means an improvement in performance is expected. The range of values between 3 and 7 indicate that no changes in performance are expected [14].

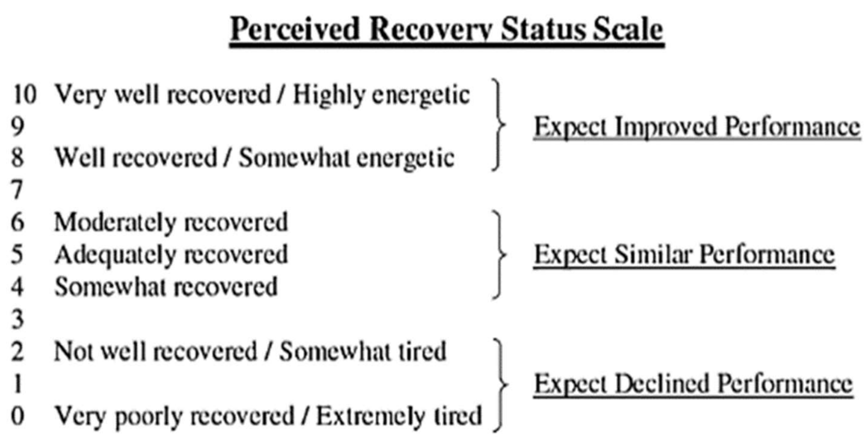

Figure 2. The Perceived Recovery Status Scale according to Laurent et al. [14].

2.6. Countermovement jump height

For the Countermovement jump height, a jump platform (JUMP SYSTEM 1.0, Cefise LTDA.), was used. The athlete was positioned, barefoot, in the interior of platform, with hands fixed at the waist. The test consisted of realizing a maximal vertical jump, with a free countermovement. Two jumps were realized with a 1-minute interval. It was considered the highest jump in centimeters

2.7. Statistical analysis

The Shapiro-Wilk test was used to assess data distribution. Descriptive data are presented as mean and standard deviation for all outcomes. A repeated-measures ANOVA was used to compare group means (pre, post-0, 24h, 48h, and 72h). When significant, a Bonferroni test for multiple comparisons was used. The Bartlett test was used to verify the homogeneity of variances. Cohen's d effect size (ES) was calculated to verify the magnitude of the difference between pre-test, post-test, 24h, 48h, and 72h. The ES was classified

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in the following manner: trivial (d lower than 0.10); small (d between 0.10-0.29); moderate (d between 0.30-0.49); large (d between 0.50-0.69); very large (d between 0.70-0.89), and perfect (d of 0.90 or greater). The Pearson product moment correlation was used to evaluate correlations between all outcomes. Correlation coefficient values were classified as very weak (below 0.20); weak (0.20 to 0.39); moderate (0.40 to 0.69); high (0.70 to 0.90) and very high (>0.90) [20]. The outlier labeling rule was used to detect outliers, and discrepancies. Outlier values were calculated by the difference between the 25th and 75th percentiles multiplied by a factor (2.2). The result is then subtracted from the 25th percentile and added to the 75th percentile. The IBM SPSS Statistics package (version 22.0; SPSS Inc, Armonk, NY) was used. Statistical significance was set at 5% (P≤0.05; two-tailed).

3. Results

3.1. Completion time

The average time to complete the 150 repetitions of wall ball was 613.82 (±115.03) seconds. The fastest participant completed the exercise session in 506 seconds and the slowest in 805 seconds (Table 1).

Table 1. Total group demographics.

n	8
Age (years)	28.4 ± 6.4
Body mass (kg)	80.4 ± 4.9
Height (m)	1.8 ± 0.1
VO_2 (ml/kg/min)	53.6 ± 3.5
Row 2K (sec)	447.3 ± 17.1
Back squat (kg)	139.1 ± 26.0
Back squat rel (kg/kg)	1.5 ± 0.7
Karen (sec)	613.8 ± 115.0

Note : Variables are expressed as mean and standard deviation (±) . Rel: relative (back squat/body mass).

3.2. Physiological, Biochemical, and Neuromuscular Responses

The blood lactate concentration and RPE were significantly higher post-exercise compared to the pre-exercise session (blood lactate concentration: 3.2 mmol/L ±0.6 and 17.5 mmol/L ±3.0 mmol/L; and RPE: 1.8 ±0.3 and post: 9.5 ±0.4, respectively) (Table 2).

Table 2. Comparisons of main outcomes for pre-test, post-test, 24h, 48h, and 72h.

	Pre	Post	24h	48h	72h
RPE	1.8 ± 0.3	9.5* ±0.4	-	-	-
Lactate (mmol)	3.2 ± 0.6	17.5* ± 3.0	-	-	-
Creatine Kinase (U/L)	143.2 ± 65.7	265.3 ± 133.5	338.4* ± 115.6	223.6 ± 89.3	204.3 ± 92.8
PRS general	7.9 ± 1.7	-	4.7*± 1.5	6.9 ± 0.3	7.9† ± 0.4
PRS upper limbs	7.5 ± 1.3	-	6.9 ± 1.1	8.8† ± 0.8	9.3*† ± 0.4
PRS lower limbs	7.9 ± 0.8	-	4.0* ± 2.5	5.1* ± 1.8	7.6† ± 0.5
Countermovement Jump (cm)	40.0 ± 6.9	39.0 ± 2.9	38.7 ± 1.8	40.0 ± 2.8	42.0 ± 3.4

Note : Variables are expressed as mean and standard deviation (±). *Significant difference with pre-test (p≤0.05); †Significant difference with 24h (p≤0.05). PRS: perceived recovery status scale; RPE: rate of perceived exertion.

The CK concentration 24 hours after the exercise session was significantly higher than the pre-exercise (338.4 U/L vs. 143.3 U/L, respectively) (Table 2 and Figure 1A). No significant differences were observed between 48- and 72-hours after exercise and pre-exercise concentrations (Table 2 and Figure 3). However, the effect size of pre and post-test and 24h and 48h were classified as large and very large (ES: 0.87, 85.2% and ES: 1.63, -33.9%, respectively) (Table 3).

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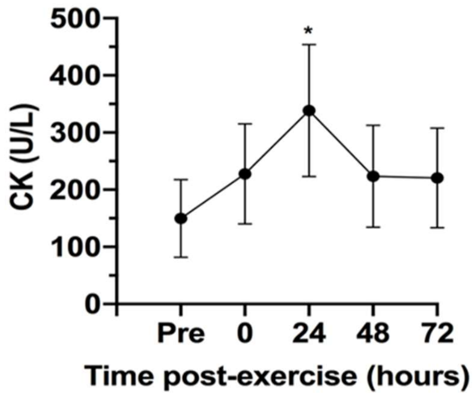

Figure 3. Variables are expressed as mean and standard deviation (±). Creatine kinase concentration (CK) results during pre-test, post-test, 24h, 48h and 72h post-test. *p ≤ 0.05 for pre.

Table 3. Effect size and percentual differences of all outcomes for the five-time assessment points (pre-test, post-test, 24h, 48h, and 72h). The PRS scales were compared between pre-test and 24h.

	PRe-Post	Post-24h	24h-48h	48h-72h
RPE	17.25 (432.0%)	-	-	-
Lactate (mmol)	3.86 (444.0%)	-	-	-
Creatine Kinase (U/L)	0.87 (85.2%)	0.74 (27.6%)	1.63 (-33.9%)	0.20 (-8.6%)
PRS general	1.82 (-40.0%)		1.67 (45.8%)	3.40 (14.3%)
PRS upper limbs	0.44 (-7.6%)		3.33 (26.3%)	1.00 (6.3%)
PRS lower limbs	1.33 (-50.7%)		0.70 (32.7%)	1.50 (47.2%)
Countermovement Jump (cm)	0.45 (-2.7%)	0.42 (-0.8%)	0.72 (3.3%)	0.13 (5.0%)

Note : Variables are expressed as percentual differences. PRS: perceived recovery scale.

There were no significant differences in CMJ height in any of the time points assessed when compared to pre-test values (immediately post, and 24h, 48h, and 72h post training) (Table 3 and Figure 4). Percentual changes between CMJ test results between pre- and post-session, post-session and 24-hours post, and 24h to 48h post session, showed effect sizes of moderate to very large magnitude (ranging from 0.42 to 0.72; -0.8% to 3.3%) (Table 3).

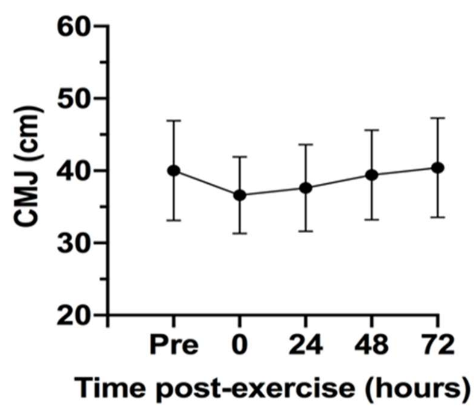

Figure 4. Variables are expressed as mean and standard deviation (±). Height of counter movement jump (CMJ) results during pre-test, post-test, 24h, 48h and 72h post-test.

Figure 5 shows the general, lower and upper limbs of the PRS pre- and post-exercise session. The scores of PRS general and PRS of the lower limbs were significantly lower in

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the 24-hours post-exercise session compared to the pre-exercise (PRS general: 4.7 ±1.5 and 7.9 ±1.7 mmol/L; and PRS of the lower limbs: 4.0 ±2.5 and 7.9 ±0.8, respectively). The PRS general, lower and upper limbs were also significantly lower at 48-post exercise compared to 72-hours post-exercise scores (Table 2 and Figure 6). The effect size for PRS scales was classified as large and very large in all-time comparisons. The only exception was the PRS for the upper limbs between pre-test and 24h (ES: 0.44, -7.6%) (Table 3).

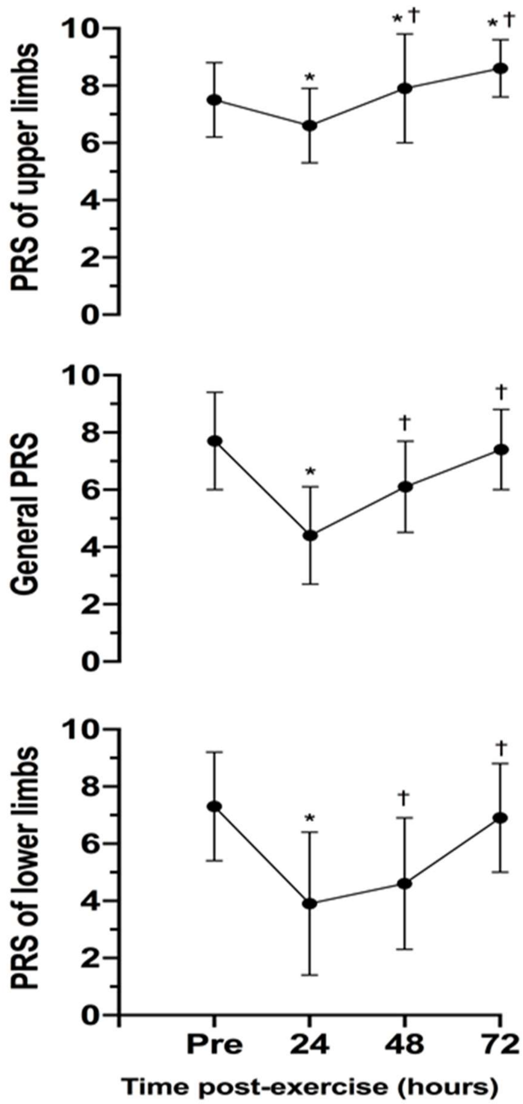

Figure 5. Variables are expressed as mean and standard deviation (±). Perceived recovery scale (PRS) of the upper limbs (UL) (A) general (B) and lower limbs (LL) results during pre-test, post-test, 24h, 48h and 72h posttest. *Significant difference with pre-test (p≤0.05); †Significant difference with 24h (p≤0.05).

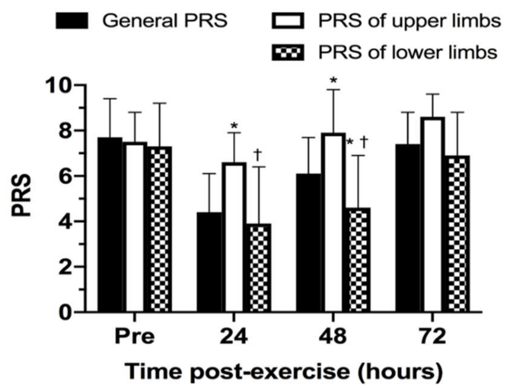

Figure 6. Variables are expressed as mean and standard deviation (±) Comparison between scores of general, lower and upper limbs of perceived recovery scale (PRS) at different time points. *p ≤ 0.05 for general PRS; † p ≤ 0.05 for PRS of upper limbs.

3.3. Correlations

At the pre-test, the CK concentration was inversely and significantly correlated with the PRS (r=-0.926; p≤0.05). In addition, the CMJ height presented a very high correlation with the PRS of the lower limbs (r=0.902; p≤0.05). There were no significant correlations between the PRS scale, CK concentration, and CMJ height immediately post-test, or at 24h, 48h, and 72h post-test.

4. Discussion

The aim of this study was to analyze the physiological, biochemical, and neuromuscular responses following a fatiguing CrossFit® benchmark session. The main findings partially confirm the initial hypothesis, revealing i) significant increases in blood lactate post-exercise; ii) an elevated CK concentration 24h post-exercise, returning to baseline levels 48h post-exercise; iii) a significant change in the participants' perceived recovery status for upper and lower limbs 24h post-exercise when compared to baseline, with PRS values for the lower and upper limbs showing different rates of recovery at 24h and 48h post exercise, with the lower limbs recovering slower than the upper limbs. The findings highlight the significant physiological, biochemical and neuromuscular changes following a CrossFit® session, and provide a better understanding of the time-course of recovery of these markers.

CrossFit® training sessions are often performed with near-maximal or maximal efforts, leading to a significant metabolic stimulus [6,8]. In this context, blood lactate concentration has been utilized as a reliable marker to assess the intensity of different sessions of CrossFit® [19]. While changes in blood lactate concentrations will be dependent on the duration and intensity of the sessions performed, previous research has shown that different CrossFit® sessions incur high blood lactate levels. Timon et al. [21] utilized two different protocols (Protocol 1: AMRAP of of Burpees and Toes to Bar increasing repetitions (1–1, 2–2, 3–3…) in five minutes; Protocol 2: three rounds of 20 repetitions of Wall Ball (9 kg) and 20 repetitions of Power Clean (a load of 40% 1RM) in the shortest possible time), with a similar lactate response in the protocol 2 as the one seen in this study (18.38±2.02 mmol/L vs 17.5 mmol/L ±3.0 mmol/L). Interestingly, protocols that do not use an external load (protocol 1) showed a smaller lactate response, even when the perception of effort was similar between sessions. It is likely that the overall intensity of the sessions elicits a high metabolic response, even in the absence of an external load. For example, a session requiring participants to complete as many rounds as possible (AMRAP) of two exercises (burpees and toes to bar) still elicited a high blood lactate response (13.3±1.87 mmol/L). Tibana et al. [6], analyzing a session that involved AMRAP of double unders and rowing, and Maté-Muñoz et al. [22] with a session that consisted of performing a single exercise (double unders), also reported a higher lactate response (9.05 ± 2.56 vs 10.37

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± 2.91 mmol/L), respectively. In addition, even when the intensity of a CrossFit® session was manipulated to be performed at a lower perception of effort (6 out of 10, utilizing the Borg CR-10 scale), the lactate responses were still quite high (12.8 ± 3.2 mmol/L) [23]. Previous studies have demonstrated that the metabolic responses induced by a training session are related to the required time to recover from this stimulus. Considering the high physiological stress induced by CrossFit® sessions, even when there is no external load, or when the intensity is controlled, understanding the time-course of recovery from these sessions is essential to ensure athletes can optimize their training.

The serum CK is often utilized to understand the recovery status of participants following a training session given its easy of collection and analysis [24]. The CK concentrations can be raised due to exercise induced muscle damage as a consequence of intense and prolonged training. The peak of serum CK normally occurs about 8h after a strength training session, and values can remain elevated for up to 96 hours when the exercise is focused on eccentric phase of the movement. Importantly, CK values have been associated with muscle injury [24,25]. Studies involving CrossFit® showed significant increases in CK, that could be pathological due the extremally high values [26,27]. The present study found increases in CK 24h post-exercise, with the values returning to baseline 48h post-exercise. These results are in agreement with Timón et al. [21] that evaluated the time course of recovery of CK in response to two different CrossFit® WODs. Both sessions induced a significant increase in CK levels 24h post-exercise, with the values decreasing and returning to baseline 48h post-exercise. Similarly, Tibana et al.[7] showed that after five workouts over three consecutive days of competition the peak of CK concentration occurred 24h post-exercise (~698.7 U/L). Thus, it seems that when the CrossFit® session don't elicit increases in CK concentration that could be considered pathological, CK concentrations might return to baseline levels within 48 hours.

In addition to changes in CK concentrations, changes in CMJ height has also been utilized as a reliable fatigue marker in different sports [10]. A recent study analyzed CMJ height as a measure to assess neuromuscular fatigue following a CrossFit® competition [7]. The CMJ jump height was significantly reduced 24-hours post competition, with the values collected at 48h and 72h post competition not different from baseline. Similarly, Tibana et al. [6] demonstrated that consecutive days of CrossFit® training, despite eliciting significant metabolic changes, did not lead to impairments in muscle power. Considering that CrossFit® sessions vary often in the exercises performed and consequently, muscle groups utilized, and their duration, it is possible that CMJ height might have limited application as a measure to monitor neuromuscular fatigue, particularly after single bouts of exercise.

While objective measures (CK and CMJ height) indicate that the participants might be fully recovered from a strenuous session within 24 to 48 hours, psychobiological monitoring of the athlete's perceived recovery state indicates that 48 to 72 hours might be needed for the athletes to return a point where performance is expected to be the similar or improved, based on the PRS. Psychobiological monitoring of training status is a non-invasive and non-exhaustive measure of assessing fitness (e. g. stress, fatigue), and also presents an effective and inexpensive measure to assess individual responses to training and competition20. Despite its possibility as a tool to monitor current training status, Bishop et al.[28] reported that there is still a limited knowledge by trainers and athletes about how to utilize such tools in different sports to optimize training intensity yielding optimal recovery in day-to-day. The results in this study show a different time course of recovery for upper and lower limbs, with the athlete's perceiving the lower limbs to require a longer recovery time. This has practical significance in CrossFit® where coaches and practitioners might use this information to prescribe the next training bout based on the athletes' perceived recovery (general, upper, and lower limbs). Moreover, the PRS can provide further information about the athletes' feelings of fatigue, lack of energy, and recovery, allowing coaches the possibility of determining the intensity of the subsequent session to reduce the level of physiologic stress and to manipulate the athlete's training load [19,23].

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Monitoring the athlete's recovery status is essential to ensure proper recovery between training sessions and optimize training prescription [24]. The results in this study demonstrate that a practical, non-invasive approach to monitoring the participant's recovery following a strenuous CrossFit® session might provide essential information for coaches and practitioners. In particular, the time-course of recovery according to the PRS is similar to that of the CK responses, with both measures reaching its most extreme values 24 hours after the training session. However, while CK responses recover faster in the subsequent 24 hours, the athletes' perceived recovery might show a slower improvement, particularly for the lower limbs based on the protocol used in this study. Therefore, this study demonstrates that the PRS may be useful in allowing appropriate adjustments in training intensity or volume in CrossFit® based on the athletes' recovery status. Athletes and CrossFit® practitioners commonly complete various training sessions throughout a week and the PRS can be used to assess the athletes' training readiness ahead of their daily session or following a programmed rest day. Considering the potentially detrimental effects of performing numerous maximal or near-maximal CrossFit® sessions in a short period of time [29], such approach can potentialize training adaptations while helping to reduce the incidence of muscle injuries and the onset of non-functional overreaching.

Some limitations of the present study must be emphasized. Particularly, the reduced numbers of participants, the lack of control over the participants' diet prior to the test must be acknowledged. In addition, caution is advised when extrapolating the results of the current study to other populations or individuals of different training experience. Future studies of a similar nature should include other critical biomarkers and an upper limb power measures to elucidate the time course of recovery and whether a state of fatigue truly occurred. Further longitudinal studies analyzing fatigue status and recovery in response to CrossFit® training in several days using similar methods can be relevant to deeper to understanding of the training inducing performance, fatigue and recovery in different subjects. Furthermore, additional studies comparing different volumes, intensities and WOD with distinct time points could improve understanding of the fatigue profile.

5. Conclusions

In summary, a single CrossFit® session using repeated wall-ball movements elicited a significant level of metabolic stress, along with an increase in CK levels in the 24-hours after the exercise session. More importantly, the results showed the potential utility of the PRS scale as noninvasive tool for accurately monitoring recovery status in CrossFit® practitioners. Coaches, sport scientists, and practitioners are advised to implement the use of the PRS to obtain important insights into the fatigue profile and recovery status of the participants. This information can be useful to coaches to optimize training prescription and to minimize the potential detrimental effects associated with the performance of repeated high-intensity sessions of CrossFit®.

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