

Communication

# Pros and Cons of Two Methods of Anaerobic Alactic Energy Assessment in a High-Intensity CrossFit® Workout

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**Abstract:** The current study aimed to evidence the strengths and weaknesses of two indirect methods for assessing the anaerobic alactic contribution to a specific CrossFit® workout. Thirty experienced crossfitters performed the Fran workout at maximal intensity, and ventilatory data were collected during the recovery period using a telemetric portable gas analyser to assess the oxygen uptake ( $\text{VO}_2$ ) of the off-kinetics fast component ( $\text{Ana}_{\text{recovery}}$ ). The kinetics of maximal phosphocreatine splitting ( $\text{Anap}_{\text{Cr}}$ ) were determined based on the literature. No differences between the two methods were observed ( $31.4 \pm 4.0$  vs.  $30.4 \pm 4.1$  kJ for  $\text{Ana}_{\text{recovery}}$  and  $\text{Anap}_{\text{Cr}}$ , respectively). Despite the existence of some caveats (e.g., errors derived from a delay at the onset of  $\text{VO}_2$  recovery and the assumption of given values in the concentration of phosphocreatine per kilogram of wet muscle, respectively) in both methods, the data indicate that they yield similar results and allow for estimations of alactic energy contribution from a short-duration and high intensity CrossFit® routine. The current data contributes to CrossFit® workout evaluations and training strategies, helping researchers to evaluate crossfitters more accurately. The advantage of the two methods used in the current study is that they are non-invasive, which differs greatly from muscle biopsies.

**Keywords:** anaerobic alactic contribution; phosphocreatine; oxygen uptake



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## 1. Introduction

Sports bioenergetics have been studied since the 1920s, with a focus on locomotion and its contribution to athletic performance [1]. The capability to produce mechanical work during physical exertion is ultimately determined by the muscle cells' ability to provide energy by means of two distinct but integrated metabolic processes: the anaerobic and the aerobic pathways [2]. Aerobic energy release is readily quantified, since there is a direct relationship between the oxygen uptake ( $\text{VO}_2$ ) measured at the mouth and the whole-body aerobic production of adenosine triphosphate [2,3]. Of the two components of anaerobic energy contribution, the lactic system is more often investigated, because it can be estimated based on the net increase in blood lactate concentration at the end of the exercise, and assumes a given energy equivalent for lactate [1,4].

The anaerobic alactic contribution has been estimated by assuming that phosphocreatine (PCr) concentration in active muscles decreases by a known amount and with a given kinetics ( $\text{Anap}_{\text{Cr}}$ ) in the transition from rest to exhaustion [2,5]. Another anaerobic alactic contribution estimation is calculated based on the postexercise  $\text{VO}_2$  fast component ( $\text{Ana}_{\text{recovery}}$ ), since the greatest part of the  $\text{O}_2$  debt has been interpreted as the energy

necessary to rebuild the high energy phosphate compounds which were split at the exercise onset [3,6]. These methods have been applied before in different exercise modes [7–9], and are based on questionable assumptions, such as the PCr concentration rest value and  $\text{VO}_2$  on response time constant at the muscular level. Moreover, the assumption that the post-exercise  $\text{VO}_2$  fast component is independent of blood lactic acid removal has also been questioned [2].

CrossFit® workouts comprise functional movements performed at high intensity, and are typically composed of gymnastic-type exercises, metabolic-related conditioning and weightlifting [10,11]. Fran is one of the most popular CrossFit® benchmarks, a time-scored workout consisting of three rounds of 21, 15 and 9 front squat to press overheads (using a 43 and 30 kg barbell for males and females, subjects dropped the hips below the knees and finished the exercise with the knees, hips and elbows in full extension) plus pull-ups (the chin needed to pass the bar) repetitions [11,12]. This workout is used to evaluate crossfitters' performance improvements, and is directly related to anaerobic thresholds obtained on a cycle ergometer [11]. Given the necessity of a more specific method to assess CrossFit® performance, the use of both aforementioned methods still warrants further research. The current study aimed to evidence the strengths and weaknesses of two methods for assessing the anaerobic alactic contribution of a specific CrossFit® workout: (i) using the  $\text{VO}_2$  off-kinetics fast component, and (ii) estimating the maximal phosphocreatine splitting in the contracting muscle.

## 2. Materials and Methods

### 2.1. Subjects and Data Collection

Thirty participants (21 males and 9 females) with  $\geq$  five years of previous CrossFit® training experience volunteered to participate in the current study ( $28.3 \pm 6.2$  and  $25.2 \pm 3.7$  years old,  $174.5 \pm 5.8$  and  $161.7 \pm 4.8$  cm of height and  $78.2 \pm 7.6$  and  $64.1 \pm 3.4$  kg of body mass, respectively). All crossfitters were instructed to maintain the same individual nutritional habits and to avoid intake of alcohol and caffeine (as well as hard physical activity) 48 h prior to the test. All volunteers were informed about the experimental procedures, associated risks and benefits of participation. The experimental procedures were approved by the Ethics Committee of the Faculty of Sport at the University of Porto (CEFAD212019), and followed the Declaration of Helsinki and the guidelines of the World Medical Association for research on humans.

The experiments were conducted at a full equipped laboratory facility with  $\sim 22$  °C room temperature and 55% relative humidity. After being familiarized with the procedures and accomplishing a 10 min individualized low intensity warm-up (joint mobility plus Fran's specific exercises), participants performed the Fran workout at maximal effort [11]. Performance was measured using a stopwatch (Seiko, Yokohama, Japan) and post-workout respiratory gas exchange was measured breath-by-breath using a portable gas analyser for five minutes (Cosmed K4b<sup>2</sup>, Cosmed, Rome, Italy) [13]. To omit errant breaths (e.g., swallowing and coughing) and to reduce the eventual noise from this acquisition, data were edited according to previously described procedures [13].

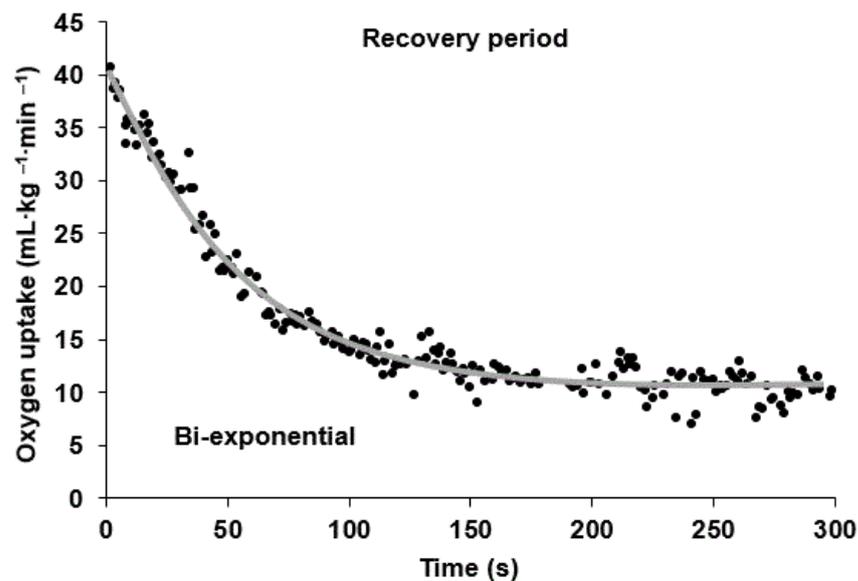
### 2.2. Data Processing

The anaerobic alactic contribution was determined using the  $\text{VO}_2$  off-kinetics fast component in the Fran workout— $\text{Ana}_{\text{recovery}}$  [3,7]. To determine the fast and slow component kinetics, mono- and bi-exponential models were computed (Equations (1) and (2)) using VO2FITTING software [14] for data analysis and treatment, as well as for editing and modelling participants' responses:

$$\text{VO}_2(t) = A_0 - H(t - \text{TD}_p) A_p (1 - e^{-(t - \text{TD}_p)/\tau_p}) \quad (1)$$

$$\text{VO}_2(t) = A_0 - H(t - \text{TD}_p) A_p (1 - e^{-(t - \text{TD}_p)/\tau_p}) - H(t - \text{TD}_{\text{sc}}) A_{\text{sc}} (1 - e^{-(t - \text{TD}_{\text{sc}})/\tau_{\text{sc}}}) \quad (2)$$

where  $VO_2(t)$  represents the relative  $VO_2$  at the time  $t$ ,  $A_0$  is the  $VO_2$  at rest,  $H$  represents the Heaviside step function,  $A_p$  and  $A_{sc}$ ,  $\tau_p$  and  $\tau_{sc}$ , and  $TD_p$  and  $T_{sc}$  are the amplitude, time constant and time delay of the off- $VO_2$  fast and slow components, respectively [14].  $Ana_{recovery}$  was determined as the  $VO_2$  time integral derived from the off-fast component, assuming an energy equivalent of  $20.9 \text{ kJ}\cdot\text{L}^{-1}$  [1,5]. Peak oxygen uptake ( $VO_{2peak}$ ) was obtained by backward extrapolation at zero recovery time using values from the first 20 s of recovery (Figure 1) [13].



**Figure 1.** Individual oxygen uptake curve during the recovery period after the Fran workout (bi-exponential model fit).

The anaerobic alactic contribution was also estimated using the maximal PCr splitting in the contracting muscle, by assuming an energy equivalent of  $0.468 \text{ kJ}\cdot\text{mM}^{-1}$  and a phosphate/oxygen ratio of 6.25 (Equation (3)) [1,5]:

$$Ana_{PCr} = PCr \cdot (1 - e^{-t/\tau}) \cdot M \quad (3)$$

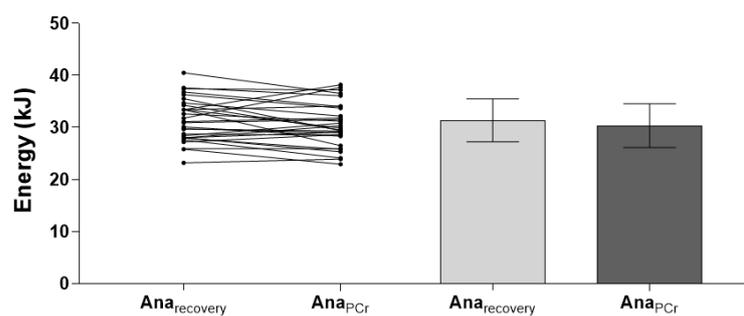
where PCr is the phosphocreatine concentration at rest, assumed to be  $18.55 \text{ mmol}\cdot\text{kg}^{-1}$  in maximally active muscle mass [7,15],  $t$  is the exercise time,  $\tau$  is time constant of the PCr splitting at exercise onset (23.4 s) and  $M$  is the body mass [1].

### 2.3. Statistical Analysis

Assuming a statistical power ( $\beta$ ) 0.90, a large effect size (0.80) and a 0.05 overall level of significance, a 19-participant sample size seemed adequate for carrying out the current study (G\*Power 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Mean plus SD were computed (GraphPad Prism 6) and data were checked for distribution normality with the Shapiro–Wilk test. The paired sample  $t$ -test was used to compare  $Ana_{recovery}$  with  $Ana_{PCr}$ , and the efficiency method agreement was assessed by linear regression analysis and Bland–Altman plot. The significance level was set at 5%.

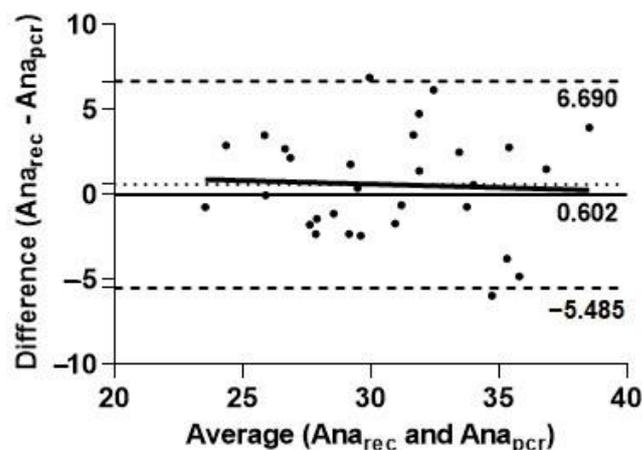
## 3. Results

The Fran workout duration was  $192 \pm 29 \text{ s}$ , while the  $VO_{2peak}$ , amplitude, time delay and time constant of the  $VO_2$  primary component during the recovery period were  $41.8 \pm 4.8$  and  $30.4 \pm 4.1 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , and  $7 \pm 5$  and  $57 \pm 14 \text{ s}$ , respectively. Figure 2 displays the individual and average values of the anaerobic alactic contribution assessed through the two used methods, with no differences being observed between  $Ana_{recovery}$  and  $Ana_{PCr}$ .



**Figure 2.** Individual and mean  $\pm$  SD values of the  $\text{VO}_2$  off-kinetics fast component and the maximal phosphocreatine splitting in the contracting muscle ( $\text{Ana}_{\text{recovery}}$  and  $\text{Ana}_{\text{PCr}}$ , respectively) methods for anaerobic alactic assessment.

The Bland–Altman plot, comparing differences between the anaerobic alactic contribution assessment methods and its average value, is reported in Figure 3. The average of the differences between methods was low and close to zero (0.29), indicating that they presented similar results. The corresponding limits of agreement (average  $\pm$  1.96 SD) ranged between  $-5.48$  and  $6.60$ , indicating a small difference between the two methods for 95% of the subjects. In addition, the Bland–Altman regression showed no differences between  $\text{Ana}_{\text{recovery}}$  and  $\text{Ana}_{\text{PCr}}$  for estimating anaerobic alactic contribution.



**Figure 3.** Bland–Altman plot comparing the two anaerobic alactic contribution assessment methods, with black dotted and dashed lines representing the 95% limits of agreement as well as the bias and linear regression (respectively).

#### 4. Discussion

The alactic anaerobic energy source contributes significantly to the specific energy expenditure requirements of short-term resistance exercises [4]. Nevertheless, its direct assessment through invasive methods, such as muscle biopsies, is expensive and complex, which is the reason why non-invasive alternatives are most frequently used [1,2]. In the current study, two methods of anaerobic alactic assessment along a CrossFit® short duration and maximal intensity workout were analysed and compared, evidencing similar values. Although none could be considered as the gold standard approach, and since both have limitations (e.g., errors derived from a delay at the onset of  $\text{VO}_2$  recovery and the assumption of given value percentage of active muscle mass), the current study underlines the importance of estimating the anaerobic alactic contribution to assess the total energy expenditure (aerobic plus anaerobic systems) of a severe-intensity exertion. This will help researchers and coaches to evaluate their crossfitters accurately, with the aim to adjust the training plan accordingly to its specificity.

The post-exercise values of the  $\text{VO}_2$  fast component amplitude and time delay were lower than those reported for other exercise modes (e.g., running, rowing and swimming) [5,7]. This may be due to the current study's higher exercise intensity and to a sport-specific  $\text{VO}_2$  answer [2,3]. Regarding the  $\text{VO}_2$  off-time constant, our results corroborate the literature conducted in other intensity domains [9,13]. The  $\text{Ana}_{\text{recovery}}$  method was first introduced by Margaria et al. [16], analysing the post-excess  $\text{VO}_2$  in the recovery period, and was referred as alactic  $\text{O}_2$  debt. Accordingly, most of the  $\text{O}_2$  debt was then interpreted as the energy necessary to rebuild high-energy phosphate compounds [6]. This interpretation has been confirmed in experiments in humans and on isolated muscle (in vivo) by assuming that PCr is rapidly resynthesized in the first 2 min after exercise [17–19]. The advantage of the  $\text{Ana}_{\text{recovery}}$  method is that it does not interfere with muscle activity during the workout, maintaining the ecological validity of the measurements. The  $\text{Ana}_{\text{recovery}}$  values reported in the current study are lower than those reported for cycling (~40 kJ), boxing (~58 kJ) and running (~40 kJ) [3,8,20], but similar than those reported to swimming (~32 kJ) and kayaking (~32 kJ) [7,21]. These differences could be attributed to different time durations and intensities of exercise, and the activation patterns of different muscle masses [2,5].

The  $\text{Ana}_{\text{PCr}}$  method considers that the energy derived from full utilization of PCr stores (during all-out efforts), which can be estimated assuming during the transition from rest to exhaustion, decreases in concentration ( $18.55 \text{ mmol}\cdot\text{kg}^{-1}$ ) in relation to the active muscle mass [1,15]. The PCr stores assumed in the current study are in accordance with the decline in PCr measured by muscle biopsy at the end of exhaustive exercise [22,23]. Thus, in contrast to the muscle biopsy method (a highly invasive procedure), this method enables an easier and more ecological estimate of the anaerobic alactic contribution [4,24]. The values of  $\text{Ana}_{\text{PCr}}$  reported in this study are similar to those described for swimming (~31 kJ), rowing (~31 kJ) and cycling (~29 kJ) events [5,7].

Although similar values were obtained using the two non-invasive methods, several limitations should be considered for both, and these could affect the estimation of alactic anaerobic energy contributions. Regarding the  $\text{Ana}_{\text{recovery}}$  method, the fact that the  $\text{VO}_2$  fast component is independent of lactic acid removal from blood during the recovery period is still a matter of debate [2]. In addition, a forced apnea during muscle contractions at the end of the workout will likely induce an augmented expiration, increasing post-workout  $\text{VO}_2$  [4,24]. There are variables that can change the values obtained by the  $\text{Ana}_{\text{PCr}}$  method, such as the percentage of active muscle mass, the associated time constant of  $\text{VO}_2$  on-response at the muscle level and the concentration of PCr per kilogram of wet muscle [1,5].

The possibility of determining the anaerobic alactic contribution is necessary to adequately assess the total energy expenditure and to relate it to high-intensity CrossFit® workout performance. In addition, CrossFit® researchers, coaches and practitioners should better understand its metabolic demands if they wish to set accurate energetic training goals with the aim of specific workout adaptations. Although there are some caveats regarding both methods, considering the absence of other (non-invasive) approaches, it is still important to estimate this variable in these types of efforts.

## 5. Conclusions

In the current study, no differences in anaerobic alactic contribution were observed between the two investigated methods, suggesting that both methods can be utilized to estimate anaerobic alactic contribution in a specific CrossFit® workout performed at maximal exertion. The advantage of determining the alactic anaerobic contribution is to maintain the ecological validity of the measurements, consequently increasing the applicability of the results. Future studies should evaluate different CrossFit® workouts performed at maximum intensity (e.g., Isabel and Grace) to clarify the eventual differences between the two methods.

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**Institutional Review Board Statement:** The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Sports of the University of Porto (approval number CEFAD 21 2019) and guidelines of the World Medical Association for research on humans.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** All of the data is contained within the article.

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