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Backward extrapolation technique: analysis of different criteria after supramaximal exercise in cycling

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RESEARCH ARTICLE

TITLE: BACKWARD EXTRAPOLATION TECHNIQUE: ANALYSIS OF DIFFERENT CRITERIA AFTER SUPRAMAXIMAL EXERCISE IN CYCLING

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RUNNING HEAD

SUPRAMAXIMAL $\dot{V}O_2$ ESTIMATION IN CYCLING

ABSTRACT

BACKGROUND: Backward extrapolation technique (BE) is used to estimate $\dot{V}O_2$ from post-exercise measuring, eliminating oronasal mask (OM) during the efforts. Despite its advantage, literature presents discrepancy in applied methods. Thus, the aim of this study is to compare different mathematical criteria to estimate values of $\dot{V}O_2$ during a supramaximal effort. Secondly, we aim to verify the effects of OM on cycling performance. Twenty-four cyclists performed three days of tests, with at least 24 h of interval between each test. Firstly, a graded exercise test was applied to determine $\dot{V}O_{2MAX}$ and your correspondent intensity ($i\dot{V}O_{2MAX}$). The second and the third day were destined to supramaximal efforts at 120% of $i\dot{V}O_{2MAX}$, performed with (SupraMASK) and without (SupraBE) oronasal mask (OM) in a randomized order. After SupraBE, OM was coupled and BE was applied. Sixty-six values of $\dot{V}O_2$ were obtained based on a linear regression fitting. We found that $\dot{V}O_{2PEAK}$

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can be estimated using different curve lengths (i.e. 20 – 60 s) but $\dot{V}O_2$ values increase exponentially with the time used in the extrapolations (i.e. < -3 s). No significant differences, trivial effects sizes, high positive correlations and low systematic errors with consistent concordance were found in the selected criteria. Despite the inconvenient use of OM, the performance was not impaired and was similar in both condition ($p = 0.84$, $ES = 0.04$). We conclude that it was possible to accurately estimate $\dot{V}O_2$ values of a supramaximal effort without any respiratory apparatus with a time-efficient analysis.

KEY-WORDS: Bicycling, oxygen consumption, exercise test, cardiorespiratory fitness, regression analyses, linear models.

Introduction

The maximal oxygen uptake ($\dot{V}O_{2MAX}$) is one of the most investigated physiological variables in exercise physiology since the early 20th century (Hale, 2008). $\dot{V}O_{2MAX}$ was usually defined as the maximum rate that the body can uptake the atmospheric oxygen in the lungs (i.e. alveolar diffusion capacity), transport through the bloodstream (i.e. by cardiovascular system) and utilize in the active tissues (i.e. mitochondrial respiration) (Green and Askew, 2018; Poole and Jones, 2017; Poole et al., 2008). In this context, $\dot{V}O_{2MAX}$ is a widely accepted method to discriminate maximal individual aerobic power (Degens et al., 2019; Gordon et al., 2011; Rodríguez et al., 2017), characterized as an important variable in sports science (e.g. evaluation, prescription and monitoring of training) (Basset and Howley, 2000; Bentley and McNaughton, 2003; Seiler and Kjerland, 2006; Stoggl and Sperlich, 2015) and in the clinical environment (e.g. cardiorespiratory fitness index and mortality predictor) (Green and Askew, 2018; Lavie et al., 2015; Schaun, 2017).

Despite the widespread use of $\dot{V}O_{2MAX}$, discussion was raised about this phenomenon, including different criteria for its occurrence (e.g. *plateau* or verification phase) (Green and Askew, 2018; Poole and Jones, 2017). When this ceiling limit of oxygen uptake ($\dot{V}O_2$) was not reached (e.g.

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by innumerable factors, including mode of exercise and peripheral limitations) the maximal value obtained (e.g. in a single supramaximal effort) could be termed $\dot{V}O_{2PEAK}$, which is also an important measure of cardiorespiratory and neuromuscular function (Green and Askew, 2018).

$\dot{V}O_2$ values were traditionally determined by a respiratory system coupled to volunteers during the efforts (da Silva et al., 2016; Ekblom-Bak et al., 2014). The available gas analyzers were connected with inconvenient apparatus (e.g. oronasal mask or snorkel in swimming), which could compromise the mechanical movement pattern in many modalities (e.g. running and swimming), cause discomfort to participants and hamper their communication with the researchers, restricting its application (da Silva et al., 2016; Léger et al., 1980).

In attempt to estimate $\dot{V}O_2$ without any disturbing instrumentation, Di Prampero et al. (1976) proposed the backward extrapolation technique (BE). In this procedure, $\dot{V}O_2$ values were estimated from post-exercise O_2 curve (i.e. excess post-exercise oxygen consumption; EPOC) based in different mathematical adjusts (Di Prampero et al., 1976; Léger et al., 1980). The use of BE allowed free sportive pattern in field context (i.e. sport specific) (Campos et al., 2017a; Campos et al., 2017b; Kalva-Filho et al., 2015a; Kalva-Filho et al., 2015b), presenting a valid practical application. Recently, our laboratory published a study comparing supramaximal running efforts (110% of $i\dot{V}O_{2MAX}$) using the traditional $\dot{V}O_2$ collection (i.e. oronasal mask; restricted bouts) and with unimpeded efforts by the BE (de Andrade et al., 2020). The authors found a 16% improvement in time to exhaustion for BE group and pointed out due to the unrestricted access to ambient air and attenuated sensation of fatigue.

Due to its advantages, BE was applied in different modalities, including running (de Andrade et al., 2020), cycling (Sleivert and Mackinnon, 1991), swimming (Campos et al., 2017a; Campos et al., 2017b; Costill et al., 1985; Kalva-Filho et al., 2015a; Kalva-Filho et al., 2015b; Montpetit et al., 1981), kayaking (Carré et al., 1994), speed skating (Di Prampero et al., 1976), in female soccer

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players (Mascarin et al., 2018) and in gymnasts (Marina and Rodriguez, 2014). However, the literature presents a widely discrepancy in the applied methods. Di Prampero et al. (1976) used an exponential least square fitting, while Léger, Seliger e Brassard (1980) proposed different equations (linear and exponential fitting). Other different criteria can be found in literature, including equations that considered the time lag for connecting the participant to the breathing valve (about three seconds) (Léger et al., 1980) and with a wide range of efforts and periods of analysis (Costill et al., 1985; Jürimäe et al., 2007; Sleivert and Mackinnon, 1991). The log transformation of $\dot{V}O_2$ data is also commonly used (de Andrade et al., 2020; Kalva-Filho et al., 2015a; Kalva-Filho et al., 2015b; Léger et al., 1980; Rodríguez et al., 2017) in attempt to enhance the physiological response and avoid outliers or data collection error, however, there is no consensus about the advantage of this practice.

Another issue that may affect the existing data is the equipment that $\dot{V}O_2$ was measured, including different gas analyzers technologies. The firsts studies were conducted with the traditional open-circuit Douglas Bag, which only allows $\dot{V}O_2$ values after a period of sampling (e.g. values every 20-30 seconds) (Carter and Jeukendrup, 2002). In more recent years, the development of breath-by-breath (BxB) gas analyzers allows new approaches and can improve the existing criteria, enhancing physiological values with continuous data at each respiratory cycle (Carter and Jeukendrup, 2002; Keskinen et al., 2003) and could minimize the errors of this technique. Despite the advantages of recent technologies, the validation of BE could be modified.

In this context, the divergent existing criteria and technologies used for BE limit your application and do not allow consensus about which method is the most accurate. Thus, the aim of the present study was to compare the $\dot{V}O_2$ values obtained continuously during a supramaximal effort (SupraMASK) and those obtained from BE after an unrestricted effort (SupraBE). Additionally, we aim to propose an accurate criterion of analysis based on different mathematical assumptions for further investigations in cycling. The effect of the oronasal mask (OM) in exhaustive performance was also

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tested. We hypothesize that $\dot{V}O_2$ could be accurately estimated from O_2 recovery curve and the OM could compromise cycling performance.

Materials & Methods

Participants

Twenty-four recreational male cyclists (De Pauw et al., 2013) who were regularly enrolled in national and regional competitions, voluntarily participated in this study (Mean \pm SD; age 35 ± 6 years, body mass 81.3 ± 8.9 kg, height 180 ± 6 cm). Participants were informed about procedures and their potential risks and provided written informed consent about their participation, approved previously by the Human Research Ethics Committee. The experimental procedures were conducted in accordance with the Declaration of Helsinki.

Experimental design

The experimental design lasted three days with at least 24h of recovery between the tests. On the first session, a graded exercise test (GXT) was performed to determine the maximal oxygen uptake ($\dot{V}O_{2MAX}$) and your correspondent intensity ($i\dot{V}O_{2MAX}$). Thereafter, two supramaximal exhaustive efforts at 120% of $i\dot{V}O_{2MAX}$ were applied in a randomized order. One effort was performed with OM (SupraMASK) (i.e. traditional $\dot{V}O_2$ collection) and was used as a criterion for true $\dot{V}O_{2MAX}$ (i.e. verification phase) (Midgley et al., 2009; Schaun, 2017). Also, $\dot{V}O_2$ at exhaustion ($\dot{V}O_{2PEAK}$) in SupraMASK effort was used as standard protocol for further analysis. The other supramaximal effort was performed unimpeded, without the OM (SupraBE) and was used for BE technique ($\dot{V}O_{2BE}$) analysis. During GXT and in supramaximal efforts, participants were verbally encouraged to perform maximally. **Fig. 1** shows the proposed design. All efforts were performed in participants own bicycles that were connected in an indoor cycling trainer (Powerbeam Pro Series, Cycle Ops, USA). This equipment has a resistance wheel with built-in strain gauges, enabling measurements of power in watts (W). The power was controlled online by computer software (Rouvy, VirtualTraining, Czech

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Republic). Participants were allowed to maintain they preference cadence, which was monitored by telemetric dispositive sensor (Joule GPS, Powertap, EUA).

Insert figure 1 next here

Graded exercise test

GXT was preceded of a seven minutes warm-up at 150W and therefore a progressive effort was performed with 50W increments every three minutes until voluntary exhaustion. $\dot{V}O_2$ was continually registered and $\dot{V}O_{2MAX}$ was attributed to the highest 30 s averages of the GXT (i.e. $\dot{V}O_2$ average over the final 30 s of each stage) only if a non-substantial increase was observed during Supramask (i.e. estimated value for $\dot{V}O_2$ at 120% of $i\dot{V}O_{2MAX}$ higher than $\dot{V}O_{2PEAK}$). The minimal exercise intensity at which the participant reached $\dot{V}O_{2MAX}$ was considered as $i\dot{V}O_{2MAX}$ (Billat et al., 1999) or was adjusted according Kuipers et al. (1985) when exhaustion occurred during the stages. Respiratory exchange ratio (RER) was continually monitored and maximal values were registered. Maximal heart rate (HR_{MAX}) was attributed to the highest 5 s averages during GXT (Midgley et al., 2009). The percentage of age-predicted maximal heart rate ($HR/age[\%]$) were calculated according Tanaka et al. (2001).

Supramaximal efforts

After a seven minutes warm-up at 150W, both Supramask and Suprabe were performed at 120% of $i\dot{V}O_{2MAX}$ until voluntary exhaustion. During Supramask, ventilatory analysis was performed during all effort by connecting the participant to an OM, and $\dot{V}O_{2PEAK}$ was defined as the average $\dot{V}O_2$ over the last 30 s of the test. Suprabe follow the same general procedure, however, the effort was performed without the respiratory equipment and the OM were accoupled immediately at the end of the effort. Time-to-exhaustion (T_{LIM}) was recorded in these efforts as performance index.

Data collection and processing

The OM (7450 Series Silicone V2™, Hans Rudolph Inc., USA) was connected to a gas analyzer (Quark CPET, Cosmed, Italy), allowing BxB $\dot{V}O_2$ data (i.e. every respiratory cycle). Before the

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beginning of each test the equipment was calibrated according to the specifications of the manufacturer. Briefly, it was used the ambient air, a gas of composition containing 16% O₂ and 5% of CO₂ (White Martins, Osasco, SP, Brazil) and a 3 L syringe for spirometer (Hans Rudolph Inc., USA), according to Quark CPET instruction manual. In all efforts, pulmonary gas exchange was recorded from five minutes in rest (i.e. baseline), during all effort in GXT and in SupraMASK and at recovery in SupraBE. RER were directly measured as the product between carbon dioxide production ($\dot{V}CO_2$) and $\dot{V}O_2$. Heart rate (HR) was monitored beat-by-beat using a cardiac transmitter belt (H7, Polar Electro, Finland) integrated to gas analyzer system.

Exploratory analysis and backward extrapolation technique

To discriminate the best adjustment between length of $\dot{V}O_2$ recovery curve and time to the regression extrapolation, exploratory procedures were performed, and a sequence of criteria was applied. Four criteria have been selected in an attempt to choose the highest level of similarity between our standard ($\dot{V}O_{2PEAK}$) and the proposed criteria. Once they were based in statistical precepts, they were reported in **statistical analysis** section. The numbers of $\dot{V}O_2$ values analyzed were decreasing progressively, since the first procedure was requisite for the next. Backward extrapolation technique (BE) was based in a linear regression fitting (i.e. $y = a + b * x$) including curves at each 10 s (10 to 60 s; i.e. 6 curves) and negative extrapolations at each second (0 to -10 s; i.e. 11 seconds). All analyses of BE were performed in relation to standard $\dot{V}O_2$ value obtained in the end of SupraMASK (i.e. $\dot{V}O_{2PEAK}$) and sixty-six values of $\dot{V}O_2$ were obtained (i.e. 6 curves combined with 11 seconds).

Statistical analysis

Shapiro-Wilk's test was used to confirm the normality of data, allowing the use of parametric procedures and the presentation of data through mean and standard deviation. As mentioned in the previous section, the four criteria were: **i)** no significant difference between $\dot{V}O_{2PEAK}$ and the value obtained by different regression adjustments, which was tested using the *t-test* for dependent samples;

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ii) trivial values of effect size (ES) between $\dot{V}O_2$ values (i.e., < 0.35 , as proposed by Rhea (2004)); iii) high and positive relationship between $\dot{V}O_2$ values, evidenced using the Pearson's product moment correlation coefficient (r) (i.e., > 0.70 , as proposed by Mukaka (2012)); iv) agreement between $\dot{V}O_2$ values and $\dot{V}O_{2PEAK}$, which was tested by Bland-Altman's analysis (Bland and Altman, 2010). Thus, to discriminate the best procedure for BE, a $1 \text{ mL.kg}^{-1}.\text{min}^{-1}$ cut-off value of the mean difference between procedures (i.e. systematic error; Bias) was assumed and, consequently, the smallest values of 95% limits of agreement (LoA) was considered for the conclusions. The coefficient r was also used to test the tendency between residuals and average values in the agreement analysis (i.e. heteroscedasticity). Comparison of T_{LIM} for both supramaximal exercises were made with *t-test* for paired samples, accomplished with the ES and r , as described above. Statistical Package for Social Science software, version 17.0 (SPSS 17, International Business Machine, USA) was used, and the level of significance was set at $p\text{-value} < 0.05$.

Results

Exploratory analysis

Seven participants did not reach the criteria for $\dot{V}O_{2MAX}$ and $\dot{V}O_2$ values did not drop in Supra_{MASK}. Thus, statistical analyses were carried out using 17 participants. The values obtained in GXT were summarized in **Table 1**. Performance in both supramaximal efforts were not statistically different (2.40 ± 0.61 and 2.43 ± 0.79 min for Supra_{MASK} and Supra_{BE}, respectively; $p = 0.86$, $ES = 0.04$) with moderate correlations ($r = 0.572$, $p = 0.016$) (**Fig. 2**). Mean values of $\dot{V}O_2$ obtained through different adjustments between lengths of $\dot{V}O_2$ recovery curve and times to the regression extrapolation are exhibited in **Fig. 3**. $\dot{V}O_2$ values increase exponentially with the time used in the negative extrapolations, independently of the length of the $\dot{V}O_2$ recovery curve used. The different criteria used to discriminate the best procedure for backward extrapolation technique were demonstrated in **Fig. 4**. When the regression was negative extrapolated to five or greater times, significant differences from

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$\dot{V}O_{2PEAK}$ were observed for all $\dot{V}O_2$ recovery curve used. The ES demonstrate values classified as small from the fortieth second of back extrapolation in the majority of the used $\dot{V}O_2$ recovery's curve (50, 40, 30 and 20 s). Small values of ES were also observed for the $\dot{V}O_2$ recovery's curve with 60 s of length, using negative extrapolations for zero and one second. The correlation criterion was observed for all times of extrapolation for 60, 50 and 40 s of $\dot{V}O_2$ recovery curve lengths. **Table 2** demonstrates the frequency of adjustments that met the different criteria. The curve length of 10 s do not satisfied our four statistical criteria for any extrapolated value and all curves above 20 s had at least one extrapolated time that met all statistical criteria.

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Selected adjustments

The $\dot{V}O_2$ obtained of the eight adjustments that met all statistical criteria were presented in **Fig. 5**. In addition, the statistical results were specified in **Table 3**. Although all adjustments presented acceptable levels of similarity, correlation and agreement with $\dot{V}O_{2PEAK}$, values obtained through a curve length of 60 s using an extrapolation to -3 s demonstrated the lowest LoA ($7.72 \text{ ml.kg.min}^{-1}$) with $\dot{V}O_{2PEAK}$. This curve (i.e. 60s and -3s) also have the highest correlation coefficient ($r = 0.824$). The heteroscedasticity was confirmed for all selected criteria ($r < 0.478$), and the residuals were spread without tendencies between the Bias and the upper and lower limit of LoA.

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Discussion

In an attempt to compare the $\dot{V}O_2$ values obtained directly during a supramaximal effort and those obtained from BE, establishing the most accurate criteria for $\dot{V}O_2$ estimation, we conducted an exploratory analysis based on different mathematical estimation. Supporting our first hypothesis, the main findings of the present study were that $\dot{V}O_{2PEAK}$ can be estimated using different curve lengths but $\dot{V}O_2$ values increase exponentially with the time used in the extrapolations.

The select adjustments that satisfied all proposed criteria were essentially based in curves of 20 s or higher with extrapolation times of -3 s or lesser, showing similar values with $\dot{V}O_{2PEAK}$. In this context, we argue that the eight eligible criteria could be used with a satisfactory level of confidence, although, the curve of 60 s with extrapolation to -3 s is the most accurate criterion and should be used in further investigations. Our secondary hypothesis was that performance would be compromise with the OM, however, T_{LIM} was similar in both condition (**Fig. 2**).

In the present study, we show consistent values from eight eligible criteria, presenting no significant differences (p -value > 0.417), trivial effects sizes ($ES < 0.140$), high positive correlations ($r > 0.736$) with acceptable concordance (Bias < 0.94 mL.kg.min⁻¹; LoA < 11.73 mL.kg.min⁻¹). These systematic errors (i.e. Bias) are ranged between 0.7 and 1.9%. Rodríguez et al. (2017) demonstrated mean differences higher than 3.4% in their estimative from linear BE when the same intensity of effort was applied (i.e. 200 meters front crawl), which despite consistent, are higher than found in the present study. Other congruent methodological approach of this study was the use of BXB measurements, amplifying the real responses of each respiratory cycle, compared with the Douglas bag analysis (Carter and Jeukendrup, 2002; Keskinen et al., 2003).

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The selected values for proposed exploratory analysis were based in the several previous studies, which presents different criteria (Campos et al., 2017a; Campos et al., 2017b; Costill et al., 1985; de Andrade et al., 2020; Di Prampero et al., 1976; Jürimäe et al., 2007; Kalva-Filho et al., 2015a; Kalva-Filho et al., 2015b; Léger et al., 1980; Sleivert and Mackinnon, 1991). These studies include curves ranged from one minute or higher (Di Prampero et al., 1976; Léger et al., 1980) to 20 s (Chaverri et al., 2016; Montpetit et al., 1981; Rodríguez et al., 2017), with extrapolation at time zero (i.e. y-intercept) (Léger et al., 1980) to -20 s (Rodríguez et al., 2017). Besides that, log transformation data are common. However, we found in earlier pilot study that this strategy did not improve the accuracy of our data (unpublished data). Therefore, we use the raw data, excluding only extreme outliers.

The results of the selected curves are in accordance with the most previous finds, and this interval probably is in absence of the slow component of $\dot{V}O_2$ recovery curve ($EPOC_{SLOW}$) (i.e. < 2 minutes) (Di Prampero et al., 1973; Green and Askew, 2018; Léger et al., 1980; Margaria et al., 1933), which could modify the characteristic of our fitting and consequently the prediction equation. In addition, the selected extrapolation times could be explained by time lag between the end of exercise and the coupling of the participants to the OM, which has shown to be around 3 seconds (Carré et al., 1994; Léger et al., 1980). Thus, values lesser than -3 s are undesirable and overestimate $\dot{V}O_{2PEAK}$. This affirmation is valid especially in our setting, which was conducted in laboratory environment, facilitating the coupling of the OM at the end of exercise.

Different of the most available literature (Chaverri et al., 2016; Di Prampero et al., 1976), our results present some advantages since we used separated efforts to compare estimated ($\dot{V}O_{2BE}$) and the actual values of $\dot{V}O_2$ ($\dot{V}O_{2PEAK}$) (**Fig. 1**). Rodríguez et al. (2017) utilized separate efforts and analyzed several criteria for BE, however, this study was conducted with swimmers. In swimming, the kinetics of $\dot{V}O_2$ was different from other modalities because the prone position (i.e. horizontal

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plane) and the simultaneous activation of upper and lower limbs could modify the fast and slow phases of EPOC (Koga et al., 1999; Sousa et al., 2015). Rodríguez et al (2017) also used maximal efforts in fixed distances (i.e. 200 m and 400 m). Despite these distances known to be elicited close to $\dot{V}O_{2MAX}$ values and very dependent on aerobic power (Correia et al., 2020; Rodríguez, 2000), they were influenced by pace strategies. To eliminate this bias, we used fixed intensities during all effort (i.e. 120% of $i\dot{V}O_{2MAX}$). Considering these methodological differences, their result must be interpreted with caution.

Contrary to our second hypothesis, performance was not influenced by the use of OM ($p = 0.86$) (**Fig. 2**) with almost null effects sizes ($ES = 0.04$). Thus, the theoretical discomfort and sensation of fatigue caused by OM was not detrimental in our settings. Recently, our laboratory demonstrated that performance was impaired by OM in running, compromising T_{LIM} in supramaximal efforts (unimpeded effort 16% higher) (de Andrade et al., 2020). There are several factors that separated these two modalities, however, we speculated that at least in cycling, mechanical factors are less compromised with the use of OM than in running. We found significant ($p = 0.016$) but only moderate correlations ($r = 0.572$) between performance in these efforts. This could be an indicative that participants respond different with the use of OM, increasing the variability between-subjects in SupraBE.

Through a critic overview of our results, we point as main limitation of our study the choice of laboratorial environment for tests application. Despite the controlled characteristic of these settings (i.e. whether conditions and equipment's), the ecological valid and field application is questionable. Other bias could be the level of physical fitness of the volunteers. According to De Pauw et al. (2013), they are in second level of performance, with a mean $\dot{V}O_{2MAX}$ of 4.0 ± 0.4 (L.min⁻¹) or 51.0 ± 5.5 (mL.kg⁻¹.min⁻¹). Thus, our findings cannot be fully extrapolated to elite cyclists or other modalities,

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since both the time to exhaustion in supramaximal efforts and type of effort could influence the $\dot{V}O_2$ recovery kinetics (Gaesser and Brooks, 1984; Özyener et al., 2001; Short et al., 1996).

Despite of these limitations, our results presents a great application in sports science and exercise physiology, especially for recreational cyclists, since it was possible to estimate $\dot{V}O_{2PEAK}$ without disturbing instrumentation during the efforts. Also, this application could improve the dynamics of laboratory settings, with greater number of subjects evaluated in the same period, once the time for $\dot{V}O_2$ collection was reduced to less than 60 seconds. Further researches should focus in road cycling, since athletes could perform high intensity efforts in field context with only recovery O_2 monitoring.

Conclusion

In conclusion, based on the results of our exploratory analysis, we concluded that was possible to consistently estimate the conventional $\dot{V}O_2$ values from a supramaximal effort without any respiratory apparatus and with a time efficient analysis. Therefore, we recommended the use of a 60 seconds $\dot{V}O_2$ curve analysis with a negative extrapolation for 3 seconds.

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REFERENCES

Basset, D.R. and Howley, E.D. (2000) Influence of exercise intensity on the on- and offtransient kinetics of pulmonary oxygen uptake in humans. *Medicine and Science in Sports and Exercise* **32**, 70-84.

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- Bentley, D.J. and McNaughton, L.R. (2003) Comparison of W(peak), VO₂(peak) and the ventilation threshold from two different incremental exercise tests: relationship to endurance performance. *Journal of Science and Medicine in Sport* **6**, 422-35, Dec.
- Billat, V.L., Blondel, N. and Berthoin, S. (1999) Determination of the velocity associated with the longest time to exhaustion at maximal oxygen uptake. *European Journal of Applied Physiology* **80**, 159-161.
- Bland, J.M. and Altman, D.G. (2010) Statistical methods for assessing agreement between two methods of clinical measurement. *International Journal of Nursing Studies* **47**, 931-936.
- Campos, E.Z., Kalva-Filho, C.A., Gobbi, R.B., Barbieri, R.A., Almeida, N.P. and Papoti, M. (2017a) Anaerobic Contribution Determined in Swimming Distances: Relation with Performance. *Frontiers in Physiology* **8**, 755.
- Campos, E.Z., Kalva-Filho, C.A., Loures, J.P., Manchado-Gobatto, F.B., Zagatto, A.M. and Papoti, M. (2017b) Comparison between peak oxygen consumption and its associated speed determined through an incremental test and a 400-m effort: Implication for swimming training prescription. *Science & Sports* **32**, e37-e41.
- Carré, F., Dassonville, J., Beillot, J., Prigent, J. and Rochcongar, P. (1994) Use of oxygen uptake recovery curve to predict peak oxygen uptake in upper body exercise. *European Journal of Applied Physiology* **69**, 258-261.
- Carter, J. and Jeukendrup, A.E. (2002) Validity and reliability of three commercially available breath-by-breath respiratory systems. *European Journal of Applied Physiology* **86**, 435-41, Mar.
- Chaverri, D., Iglesias, X., Schuller, T., Hoffmann, U. and Rodriguez, F.A. (2016) Estimating peak oxygen uptake based on postexercise measurements in swimming. *Applied physiology, nutrition, and metabolism* **41**, 588-96, Jun.
- Correia, R.A., Feitosa, W.G., Figueiredo, P., Papoti, M. and Castro, F.A.S. (2020) The 400-m Front Crawl Test: Energetic and 3D Kinematical Analyses. *International Journal of Sports Medicine* **41**, 21-26, Jan.
- Costill, D.L., Kowaleski, J., Porter, D., Kirwan, J., Fielding, R. and King, D. (1985) Energy Expenditure During Front Crawl Swimming. *International Journal of Sports Medicine* **6**, 266-270.
- da Silva, D.F., Nakamura, F.Y. and Machado, F.A. (2016) Efeitos do uso da máscara para análise de gases sobre variáveis fisiológicas e perceptuais máximas e submáximas durante um teste incremental. *Revista Brasileira de Educação Física e Esporte* **30**, 523-531.
- de Andrade, V.L., Kalva-Filho, C.A., Ribeiro, N.X., Gobbi, R.B., de Arruda, T.B. and Papoti, M. (2020) Determination of maximum accumulated oxygen deficit using backward extrapolation. *International Journal of Sports Medicine* **41**, 1-7.
- De Pauw, K., Roelands, B., Cheung, S.S., de Geus, B., Rietjens, G. and Meeusen, R. (2013) Guidelines to classify subject groups in sport-science research. *International Journal of Sports Physiology and Performance* **8**, 111-22, Mar.
- Degens, H., Stasiulis, A., Skurvydas, A., Statkeviciene, B. and Venckunas, T. (2019) Physiological comparison between non-athletes, endurance, power and team athletes. *European Journal of Applied Physiology* **119**, 1377-1386, Jun.
- Di Prampero, P.E., Cortili, G., Mognoni, P. and Saibene, F. (1976) Energy cost of speed skating and efficiency of work against air resistance. *Journal of Applied Physiology* **40**, 584-591.
- Di Prampero, P.E., Peeters, L. and Margaria, R. (1973) Alactic O₂ debt and lactic acid production after exhausting exercise in man. *Journal of Applied Physiology* **34**, 628-32, May.
- Eklom-Bak, E., Bjorkman, F., Hellenius, M.L. and Eklom, B. (2014) A new submaximal cycle ergometer test for prediction of VO₂max. *Scandinavian Journal of Medicine and Science in Sports* **24**, 319-26, Apr.

- Gaesser, G.A. and Brooks, G.A. (1984) Metabolic bases of excess post-exercise oxygen consumption. *Medicine and Science in Sports and Exercise* **16**, 29-43.
- Gordon, D., Hopkins, S., King, C., Keiller, D. and Barnes, R.J. (2011) Incidence of the plateau at VO₂max is dependent on the anaerobic capacity. *International Journal of Sports Medicine* **32**, 1-6, Jan.
- Green, S. and Askew, C. (2018) VO₂peak is an acceptable estimate of cardiorespiratory fitness but not VO₂max. *Journal of Applied Physiology* **125**, 229-232, Jul 1.
- Hale, T. (2008) History of developments in sport and exercise physiology: A. V. Hill, maximal oxygen uptake, and oxygen debt. *Journal of Sports Science* **26**, 365-400, Feb 15.
- Jürimäe, K.H., Haljaste, K., Cicchella, A., Lätt, E., Purge, P., Leppik, A. and Jürimäe, T. (2007) Analysis of Swimming Performance. *Pediatrics and Exercise Science* **19**, 70-81.
- Kalva-Filho, C.A., Campos, E.Z., Andrade, V.L., Silva, A., Zagatto, A.M., Lima, M. and Papoti, M. (2015a) Relationship of aerobic and anaerobic parameters with 400 m front crawl swimming performance. *Biology of Sport* **32**, 333-337, Dec.
- Kalva-Filho, C.A., Santiago, P.R.P., Zagatto, A.M., Da Silva, A.S.R., Araújo, M.I.C., Gobbato, C.A. and Papoti, M. (2015b) Relationship between aerobic and anaerobic parameters from 3 minutes all out and 400m performance. *Journal of Strength and Conditioning Research* **29**, 238-245.
- Keskinen, K.L., Rodriguez, F.A. and Keskinen, O.P. (2003) Respiratory snorkel and valve system for breath-by-breath gas analysis in swimming. *Scandinavian Journal of Medicine and Science in Sports* **13**, 322-329, Oct.
- Koga, S., Shiojiri, T., Shibasaki, M., Kondo, N., Fukuba, Y. and Barstow, T.J. (1999) Kinetics of oxygen uptake during supine and upright heavy exercise. *Journal of Applied Physiology* **87**, 253-260.
- Kuipers, H., Verstappen, F.T., Keizer, H.A., Geurten, P. and van Kranenburg, G. (1985) Variability of aerobic performance in the laboratory and its physiologic correlates. *International Journal of Sports Medicine* **6**, 197-201, Aug.
- Lavie, C.J., Arena, R., Swift, D.L., Johannsen, N.M., Sui, X., Lee, D.C., Earnest, C.P., Church, T.S., O'Keefe, J.H., Milani, R.V. and Blair, S.N. (2015) Exercise and the cardiovascular system: clinical science and cardiovascular outcomes. *Circulation Research* **117**, 207-19, Jul 3.
- Léger, L., Seliger, V. and Brassard, L. (1980) Backward extrapolation from O₂ recovery. *Medicine and Science in Sports and Exercise* **12**, 24-27.
- Margaria, R., Edwards, H.T. and Dill, D.B. (1933) Mechanisms of contracting and paying the oxygen debt and the role of lactic acid in muscular contraction. *Journal of Applied Physiology* **106**, 689-715.
- Marina, M. and Rodriguez, F.A. (2014) Physiological demands of young women's competitive gymnastic routines. *Biology of Sport* **31**, 217-22, Aug.
- Mascarin, R.B., De Andrade, V.L., Barbieri, R.A., Loures, J.P., Kalva-Filho, C.A. and Papoti, M. (2018) Dynamics of Recovery of Physiological Parameters After a Small-Sided Game in Women Soccer Players. *Frontiers in Physiology* **9**, 887.
- Midgley, A.W., Carroll, S., Marchant, D., McNaughton, L.R. and Siegler, J. (2009) Evaluation of true maximal oxygen uptake based on a novel set of standardized criteria. *Appl Physiol Nutr Metab* **34**, 115-23, Apr.
- Montpetit, R.R., Léger, L., Lavoie, J. and Cazorla, G. (1981) VO₂ Peak During Free Swimming Using the Backward Extrapolation of the O₂ Recovery Curve. *European Journal of Applied Physiology* **47**, 385-391.

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- Mukaka, M.M. (2012) Statistics Corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal* **24**, 69-71.
- Özyener, F., Rossiter, H.B., and, S.A. and Whipp, B.J. (2001) Influence of exercise intensity on the on- and offtransient kinetics of pulmonary oxygen uptake in humans. *Journal of Physiology* **533**, 891-902.
- Poole, D.C. and Jones, A.M. (2017) Measurement of the maximum oxygen uptake $\text{Vo}_{2\text{max}}$: $\text{Vo}_{2\text{peak}}$ is no longer acceptable. *Journal of Applied Physiology* **122**, 997-1002, Apr 1.
- Poole, D.C., Wilkerson, D.P. and Jones, A.M. (2008) Validity of criteria for establishing maximal O_2 uptake during ramp exercise tests. *European Journal of Applied Physiology* **102**, 403-10, Mar.
- Rhea, M.R. (2004) Determining the magnitude of treatment effects in strength training research through the use of the effect size. *Journal of Strength and Conditioning Research* **18**, 918-920.
- Rodríguez, F.A. (2000) Maximal oxygen uptake and cardiorespiratory response to maximal 400-m free swimming, running and cycling tests in competitive swimmers. *The Journal of Sports Medicine and Physical Fitness* **40**, 87-95.
- Rodríguez, F.A., Chaverri, D., Iglesias, X., Schuller, T. and Hoffmann, U. (2017) Validity of Postexercise Measurements to Estimate Peak VO_2 in 200-m and 400-m Maximal Swims. *International Journal of Sports Medicine* **38**, 426-438, Jun.
- Schaun, G.Z. (2017) The Maximal Oxygen Uptake Verification Phase: a Light at the End of the Tunnel? *Sports Medicine - Open* **3**, 44, Dec 8.
- Seiler, K.S. and Kjerland, G.O. (2006) Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? *Scandinavian Journal of Medicine and Science in Sports* **16**, 49-56, Feb.
- Short, K.R., Wiest, J.M. and Sedlock, D.A. (1996) The Effect of Upper Body Exercise Intensity and Duration on Post-Exercise Oxygen Consumption. *International Journal of Sports Medicine* **17**, 559-563.
- Sleivert, G. and Mackinnon, L.T. (1991) The validation of backward extrapolation of submaximal oxygen consumption from the oxygen recovery curve. *European Journal of Applied Physiology* **63**, 135-139.
- Sousa, A., Rodriguez, F.A., Machado, L., Vilas-Boas, J.P. and Fernandes, R.J. (2015) Exercise modality effect on oxygen uptake off-transient kinetics at maximal oxygen uptake intensity. *Experimental Physiology* **100**, 719-29, Jun.
- Stoggl, T.L. and Sperlich, B. (2015) The training intensity distribution among well-trained and elite endurance athletes. *Frontiers in Physiology* **6**, 295.
- Tanaka, H., Monahan, K.D. and Seals, D.R. (2001) Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology* **37**, 153-156.

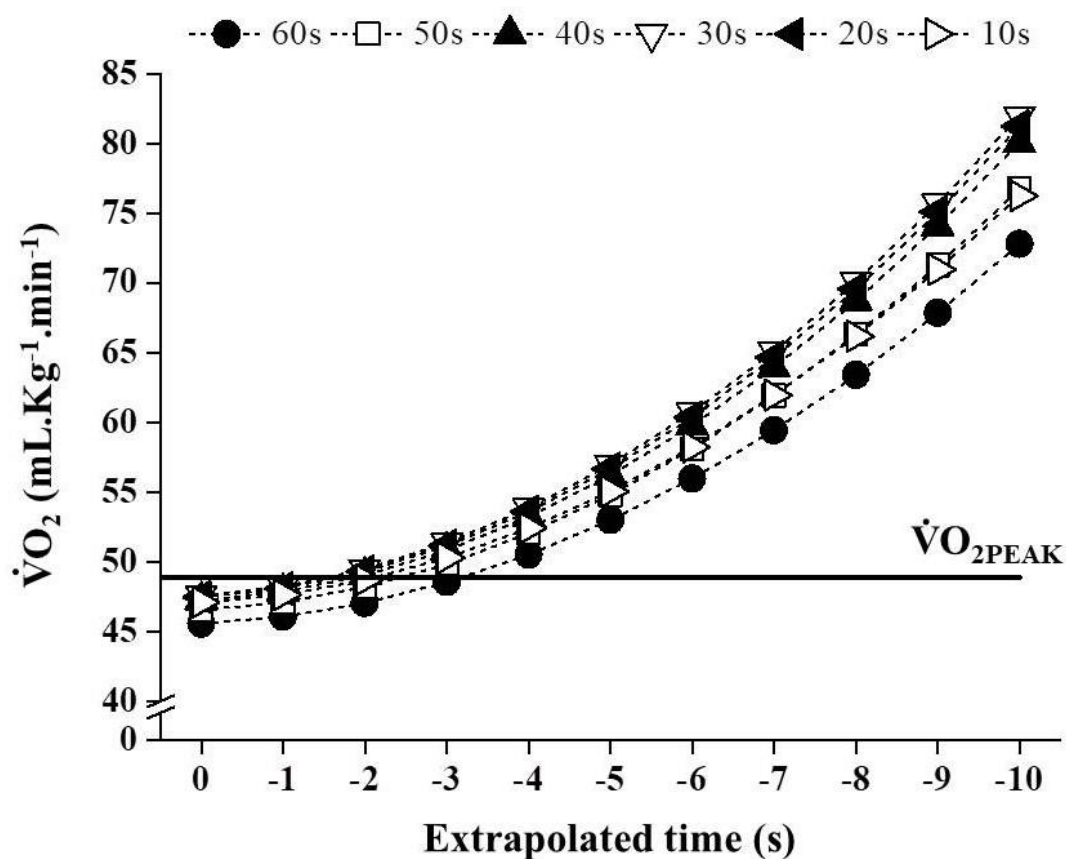


Figure 1. performance in both supramaximal efforts with (Supramask) and without (Suprabe) OM. Dots represents individual data in each performance test; p value obtained using t-test for paired samples.

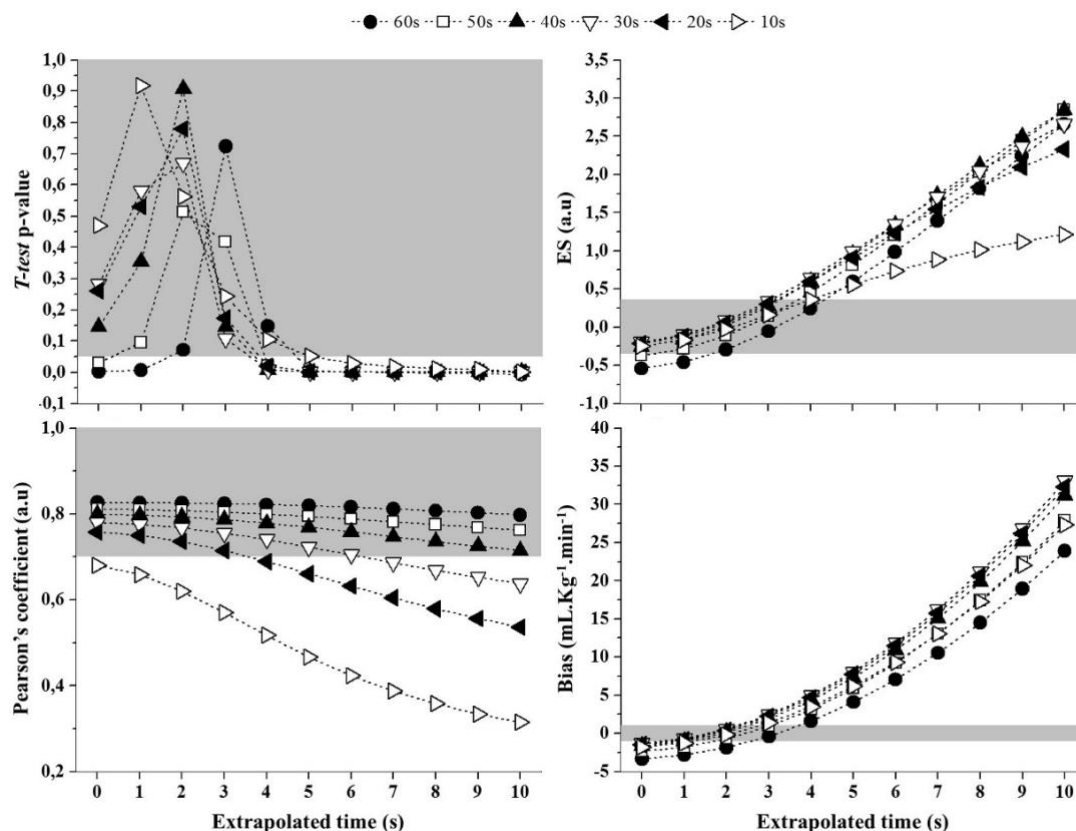


Figure 2. Mean values of oxygen consumption ($\dot{V}O_2$) obtained with different length of recovery curve (i.e., 10 – 60 s) and with several negative regressions (i.e., 0 – 10 s). The solid horizontal line represents the mean value of the maximal oxygen consumption observed during a supramaximal exhaustive effort ($\dot{V}O_{2PEAK}$).

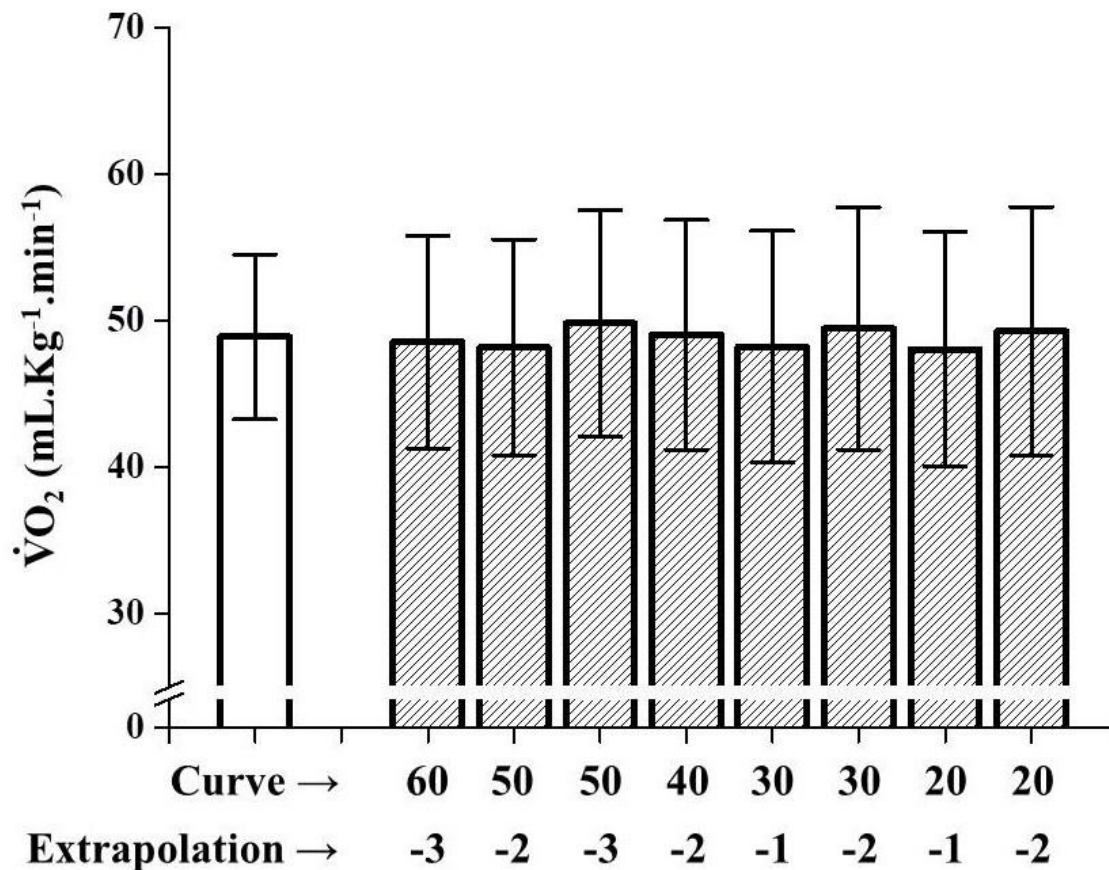


Figure 3. Statistical criteria used to discriminate the best procedure for backward extrapolation technique. The values were obtained with different lengths of recovery curve (i.e., 10 – 60 s) and with several negative regressions (i.e., 0 – 10 s). The gray area represents the pre-establish cut-offs for the different criteria (see statistical analysis section).

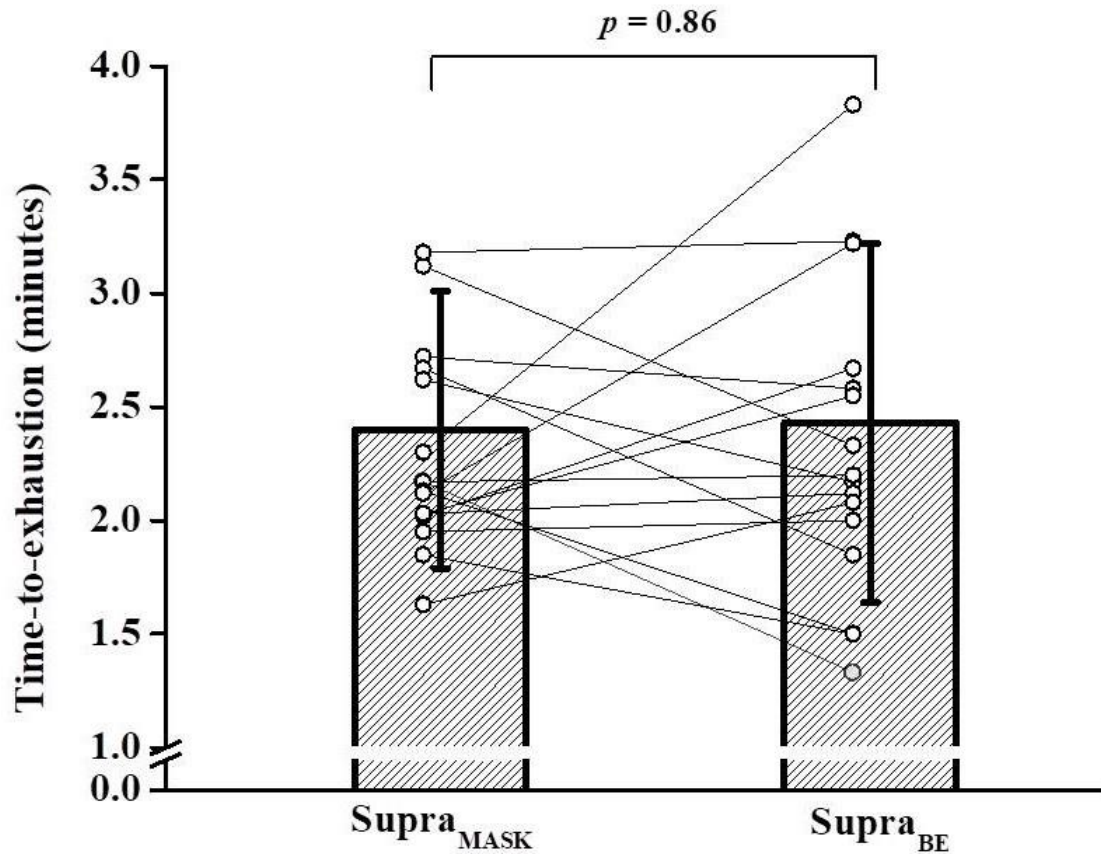


Figure 4. Mean and standard deviation values of oxygen consumption ($\dot{V}O_2$) determinate through the eight adjustments that met statistical criteria. These adjustments varied by curve length and the time used to back extrapolations. White bar represents the oxygen consumption after a supramaximal effort with OM ($\dot{V}O_{2PEAK}$) (i.e. standard criteria).

Table 1. Physiological parameters obtained after graded exercise test (GET).

Parameter	Mean	SD
$\dot{V}O_{2MAX}$ (L.min ⁻¹)	4.0	0.4
$\dot{V}O_{2MAX}$ (mL.kg ⁻¹ .min ⁻¹)	51.0	5.5
i $\dot{V}O_{2MAX}$ (W)	301	26
RER (arbitrary unit)	1.1	0.1

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HR _{MAX} (beats.min ⁻¹)	182	6
HR/age (%)	99	4

$\dot{V}O_{2MAX}$ (L.min⁻¹): maximal oxygen uptake; $\dot{V}O_{2MAX}$ (mL.kg⁻¹.min⁻¹): maximal oxygen uptake relative to body mass; $i\dot{V}O_{2MAX}$ (W): intensity correspondent to $\dot{V}O_{2MAX}$; RER (arbitrary unit): maximal respiratory exchange ratio; HR_{MAX} (beats.min⁻¹): maximal heart rate; HR/age (%): percentage of age-predicted maximal heart rate.

Table 2. Frequency of oxygen consumption values obtained by negative extrapolations that met the statistical criteria in the different $\dot{V}O_2$ recovery curve lengths (10 s a 60 s).

Statistical criteria					
	Differences	ES	Correlation	Bias	Extrapolations
10 s	6	4	0	0	----
20 s	4	4	4	2	-1 and -2 s
30 s	4	4	4	2	-1 and -2 s
40 s	4	4	4	1	-2 s
50 s	3	3	3	2	-2 and -3 s
60 s	3	3	3	1	-3 s

Differences: no difference with the $\dot{V}O_2$ obtained at the end of supramaximal exercise (*t* test); ES: effect size value smaller than 0.35; Correlation: Pearson's coefficient positive and higher than 0.70; Bias: mean difference between procedures smaller than 1 mL.kg⁻¹.min⁻¹; Extrapolation: times that the regression was back extrapolated and met the statistical criteria.

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Table 3. Specifications of statistical criteria observed for the eight selected adjustments of backward extrapolation technique. All procedures were performed in relation of the maximal values observed at the end of supramaximal effort.

Adjustment		Statistical criteria			
Curve	Extrapolation	Differences	ES	<i>r</i>	Bias \pm LoA95
Length (s)	Time (s)				(mL.kg ⁻¹ .min ⁻¹)
60 s	-3 s	0.723	- 0.055	0.824	- 0.36 \pm 7.72
50 s	-2 s	0.513	- 0.108	0.807	- 0.71 \pm 7.86
50 s	-3 s	0.417	0.140	0.804	0.94 \pm 10.05
40 s	-2 s	0.901	0.020	0.793	0.14 \pm 9.56
30 s	-1 s	0.581	- 0.101	0.775	- 0.69 \pm 9.14
30 s	-2 s	0.669	0.081	0.767	0.57 \pm 11.07
20 s	-1 s	0.530	- 0.121	0.750	- 0.83 \pm 9.61
20 s	-2 s	0.779	0.056	0.736	0.40 \pm 11.73

Differences: no difference with the $\dot{V}O_2$ obtained at the end of supramaximal exercise (*t* test); ES: effect size; *r*: Pearson's product moment correlation coefficient; Bias: mean difference between procedures; LoA: 95% limits of agreement.