“VO₂ at Maximal and Supramaximal Intensities: Lessons to High Interval Training in Swimming”
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Abstract

**Purpose:** To establish appropriate work intensity for interval training that would elicit maximal oxygen uptake (VO$_{2\text{max}}$) for well-trained swimmers. **Methods:** 12 male competitive swimmers completed an incremental protocol to determine the minimum velocity at VO$_{2\text{max}}$ (vVO$_{2\text{max}}$) and, in randomized order, three square wave exercises from rest to 95, 100 and 105% of vVO$_{2\text{max}}$. Temporal aspects of the VO$_2$ response were examined in these latter. **Results:** Swimming at 105% of vVO$_{2\text{max}}$ took less (p<0.04) absolute time to achieve 90, 95 and 100% of VO$_{2\text{max}}$ intensities (35.0±7.7, 58.3±15.9, 58.3±19.3 s) compared with 95 (72.1±34.3, 106.7±43.9, 151.1±52.4 s) and 100% (55.8±24.5, 84.2±35.4, 95.6±29.8 s) of VO$_{2\text{max}}$. However, swimming at 95% of vVO$_{2\text{max}}$, resulted in longer absolute time (p<0.001) at or above the desired intensities (90%: 268.3±72.5, 95%: 233.8±74.3, 100%: 173.6±78.2 s) and more relative time at or above 95% of VO$_{2\text{max}}$, than the 105% of vVO$_{2\text{max}}$ (68.6±13.5 vs 55.3±11.5%, p<0.03), and at or above 100% of VO$_{2\text{max}}$, than the 100 and 105% of vVO$_{2\text{max}}$ (52.7±16.3 vs 28.2±10.5 and 34.0±11.3%, p<0.001). At 60s of effort, swimmers achieved 85.8±11.2, 88.3±5.9, and 94.7±5.5% of the VO$_{2\text{max}}$ when swimming at 95, 100, and 105% of vVO$_{2\text{max}}$, respectively. **Conclusions:** When training to elicit VO$_{2\text{max}}$, using higher swimming intensities will promote a faster VO$_2$ response but a shorter time spent above these intensities. However, lower intensities allow maintaining the desired response for a longer period of time. Moreover, using the 60s time period seem to be a more adequate stimulus than shorter ones (~30s), especially when performed at 105% of vVO$_{2\text{max}}$ intensity.
Introduction

Interval training was firstly described by Reindell and Roskamm and popularized in the 1950s by the Olympic champion Emil Zatopek (1). One successful method of performing higher volumes of high-intensity training is termed high intensity interval training (HIIT). This is defined as repeated bouts of high-intensity exercise (i.e. from maximal lactate steady state or second ventilatory threshold to ‘all-out’ supramaximal exercise intensities), interspersed with recovery periods of low-intensity exercise or complete rest (2). The minimum velocity associated with maximal oxygen consumption (vVO$_{2max}$) is a parameter used as a guide for prescribing training intensities for optimal improvement in cardiorespiratory fitness, as it is a relevant indicator of performance of middle and long distance events (3,4). Interval training based on this velocity has been proposed to be an efficient mean of improving both aerobic power and vVO$_{2max}$ in endurance sports (1).

It has been recommended that the optimal improvement in cardiorespiratory fitness performance relays on a certain amount of training at intensities corresponding to 90-100% VO$_{2max}$ (5), where the time spent $\geq$ 90 and $\geq$ 95% VO$_{2max}$ is used as criteria to judge the effectiveness of the training stimulus (6-8). Performance of continuous work at these intensities cannot be sustained for a long time, and thus, limits total training time at these intensities in a single training session (8). However, the analysis of continuous work at such high intensities could provide a better understanding of the different cardiorespiratory responses that might occur. The reported slower VO$_2$ kinetics of swimming (on- and off-transients) compared with other exercise modes (e.g. cycling and running) (9,10), as well as the narrow range of submaximal speeds within the exercise intensity domains in swimming (11), suggests that the most effective range of velocities for the improvement of VO$_{2max}$ in this specific exercise mode might be different.
Moreover, the VO$_2$ responses during interval training in swimming differ from those reported on running and cycling$^7$, and therefore, cannot be applied to the former.

On the other hand, the use of a fraction of time to exhaustion has been proposed as a way to individualize training prescription, to provide greater improvement in aerobic fitness$^6$. This prescription method underlines that the most adequate duration in intermittent runs at vVO$_{2\text{max}}$ was ½ of time to exhaustion (Tlim). Based on that, Billat et al.$^{12}$ showed improvements in the VO$_{2\text{max}}$ and the vVO$_{2\text{max}}$ in trained runners after only four weeks. Considering the reports of similar Tlim at vVO$_{2\text{max}}$ intensity among different exercises modes, where swimming was one of the mode considered$^{9,13}$, may suggest that work-duration at vVO$_{2\text{max}}$ could be similar among exercise modes and that the knowledge of the VO$_2$ response of running or cycling can be directly applied to swimming. Therefore, the effectiveness of a HIIT duration in swimming is still a matter of debate, since its distinct VO$_2$ kinetics but similar Tlim compared with the other modes of exercise, can mislead the establishment of the appropriate work intensity.

The aim of this study was to establish an appropriate work intensity for HIIT that would elicit VO$_{2\text{max}}$ for well-trained swimmers, by examining the temporal aspects of the VO$_2$ response at 95, 100 and 105% vVO$_{2\text{max}}$ constant intensity.

**Methods**

**Subjects**

Twelve national level competitors’ male swimmers (mean ± SD; age: 18.2 ± 4.1 yrs, height: 1.79 ± 0.65 m and body mass: 70.5 ± 5.8 kg) volunteered to participate in this study. All swimmers were specialized in freestyle middle distance events (200/400/800m), trained at least eight times per week and had been regularly involved in competitive events at national level for at least three years. All participants (or parents/guardians when subjects were under 18 yrs)
provided informed written consent, and subjects avoided strenuous exercise in the 24 h before each testing session (conducted at the same time of the day for each subject and separated by at least 24 h), and were well hydrated and abstained from food, caffeine, and alcohol in the 3 h before testing. The Institutional Ethical Review Board, approved the study design and this has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

**Design**

The protocol involved four visits to the swimming pool facilities over a two-week period. In the first session, each swimmer performed an individualized intermittent incremental protocol for front crawl VO$_{2\text{max}}$ and vVO$_{2\text{max}}$ assessment, with increments of 0.05 m s$^{-1}$ and 30 s rest intervals between each 200m stage until exhaustion, with initial velocity set at the individuals’ performance on the 400-m freestyle, followed by seven increments of velocity$^{14}$. The velocity was controlled at each stage by a visual pacer with flashing lights in the bottom of the pool (TAR.1.1, GBK electronics, Aveiro, Portugal). For visits 2-4, subjects performed a single square-wave transition exercises from rest to different percentages of VO$_{2\text{max}}$ velocity (95, 100 and 105%) to volitional exhaustion, which were presented in random order. This test consisted of three distinct phases: (i) 10-min warm-up exercise at 50% of the vVO$_{2\text{max}}$; (ii) 5-min recovery; and (iii) the maintenance of the different percentages of VO$_{2\text{max}}$ intensity until exhaustion to determine the Tlim. These square wave tests ended when the swimmers could no longer maintain the required velocity dictated by the aforementioned visual feedback. Encouragement was given to motivate the swimmers to perform their best effort in both protocols.
Methodology

All test sessions took place in a 25-m indoor swimming pool with a water temperature of 27.5°C and in-water starts and open turns, without underwater gliding, were used. Respiratory and pulmonary gas-exchange variables were continuously measured using a telemetric portable breath-by-breath gas analyzer (K4b², Cosmed, Rome, Italy) that was suspended over the water (at a 2-m height) in a steel cable, following the swimmer along the pool, minimizing disturbances of the normal swimming movements. This equipment was connected to the swimmer by a low hydrodynamic resistance respiratory snorkel and valve system (Aquatrainer, Cosmed, Italy; for a more detailed description and developing process, refer to Sousa and co-workers 15). The gas analyzer was calibrated before each test with gases of known concentration (16% O₂ and 5% CO₂) and the turbine volume transducer calibrated with a 3-L syringe, following a standard certified commercial gas preparation (“K4b² use manual” Cosmed Ltd., 2011 44–47). Capillary blood samples (25 μL) for blood lactate concentration [La⁻] analysis were collected from the earlobe during the 30 s intervals (intermittent incremental protocol) and immediately at the end of exercise at minute 1, 3, 5 and 7 of the recovery period, until maximal values were reached ([La⁻]max), in both intermittent incremental protocol and square wave transition exercises (Lactate Pro, Arkay, Inc., Kyoto, Japan).

VO₂max was considered to be reached according to primary and secondary criteria 16 (intermittent incremental protocol) and all ventilatory parameters mean values were measured over the last 60 s of the exercise, in both protocols.

Data Analysis

Firstly, occasional VO₂ breath values were omitted from the analysis (caused by swallowing, coughing, sighing, signal interruptions and so forth) by including only those in-
between VO₂ mean ± standard deviation. After verification of the data, individual breath-by-breath VO₂ responses were smoothed by using a 3-breath moving average and time-average of 5s, using the time-averaging function of the Cosmed analysis software (Cosmed, Rome, Italy) 17.

The temporal parameters of the VO₂ response during all square-wave transition exercises considered were: (i) the percentage of Tlim spent to attain 90, 95 and 100% VO₂max (90% VO₂max, 95% VO₂max and 100% VO₂max, respectively); (ii) the time of Tlim spent at intensities ≥90%VO₂max (≥90), ≥95%VO₂max (≥95) and ≥100%VO₂max (≥100); and (iii) the percentage of VO₂max at 30s time period (t30) and at 60s time period (t60). The VO₂ response parameters during the recovery period (done passively inside the swimming pool) after all square-wave transition exercises considered were the time necessary to achieve 50% VO₂max (50%VO₂max) and t30 and t60. A representative VO₂ kinetics curve with the temporal parameters measures is shown in Figure 1.

**Statistical Analysis**

Shapiro-Wilk test confirmed the data normality and homogeneity, and were presented as mean ± SD. The differences in ventilatory, metabolic, performance and temporal parameters between the square-wave transition exercises performed at 95, 100 and 105% of vVO₂max intensity were tested for statistical significance using ANOVA for repeated measures. Significant effects were further explored using Bonferroni post hoc procedures. Magnitudes of standardized effects (η²) were determined against the following criteria: small, 0.2–0.5; moderate, 0.5–0.8 and large, >0.8. All statistical procedures were conducted with SPSS 21.0 and the significance level was set at 5%.
Results

The individual and mean values of the Tlim responses at each studied condition is shown in Figure 2.

The mean VO\textsubscript{2} values for the incremental protocol and square-wave transition exercises were similar ($\eta^2=0.15$), although the different intensity had an effect on the mean [La\textsuperscript{−}]\textsubscript{max} values ($p=0.006$, $\eta^2=0.31$) since they were ~16 and ~8% higher in 100 and 105% vVO\textsubscript{2max} tests (respectively) compared with the incremental protocol. As expected, the work intensity had an effect on the mean Tlim values ($p<0.001$, $\eta^2=0.69$), which were ~18 and ~43% ($\eta^2=0.80$) higher at 95% of vVO\textsubscript{2max} compared with 100 and 105% tests, respectively.

Table 1 shows the temporal parameters of the VO\textsubscript{2} response during the square-wave transition exercises performed at 95, 100 and 105% vVO\textsubscript{2max}.

In the 90%VO\textsubscript{2max} parameter, the absolute time was ~105 and ~57% lower in the 95 and 100% of vVO\textsubscript{2max} intensities (respectively) compared with the highest intensity ($p=0.004$, $\eta^2=0.39$). This trend was also observed for the absolute≥90 parameter, which was higher in the 95 and 100% of vVO\textsubscript{2max} intensities compared with 105% of vVO\textsubscript{2max} ($p<0.001$, $\eta^2=0.87$). In addition, these two intensities evidenced differences between themselves.

The 95%VO\textsubscript{2max} relative and absolute parameter was ~23% lower ($p=0.02$, $\eta^2=0.30$) and ~84% higher ($p=0.005$, $\eta^2=0.38$) for the 95% of vVO\textsubscript{2max} compared with 105% of vVO\textsubscript{2max} intensity. The ≥95 relative parameter was ~16% higher when swimming at 95% compared with the 105% square-wave transition exercise. However, when absolute values were considered, swimming at 105% of vVO\textsubscript{2max} needed less time to achieve the 95%VO\textsubscript{2max} intensity compared with 95 and 100% of vVO\textsubscript{2max} ($p<0.001$, $\eta^2=0.84$). In addition, these two latter intensities evidenced differences between themselves.
To achieve the 100% VO$_2$$_{max}$ intensity, subjects needed ~37% more of the Tlim total time at 100% of vVO$_2$$_{max}$ compared with the 105% of vVO$_2$$_{max}$ intensity ($p=0.04$, $\eta^2=0.18$). However, when absolute values were considered, 95% of vVO$_2$$_{max}$ was the intensity that needed more time to achieve the 100% VO$_2$$_{max}$ compared with the 100 and 105% of vVO$_2$$_{max}$ intensities ($p<0.001$, $\eta^2=0.74$). In addition, these two latter intensities evidenced differences between themselves. The $\geq$100 parameter was ~87 and ~58% higher in the 95% of vVO$_2$$_{max}$ compared with the 100 and 105% of vVO$_2$$_{max}$ intensities, respectively ($p<0.001$, $\eta^2=0.54$). This same trend was observed for the absolute values ($p<0.001$, $\eta^2=0.75$).

Swimming at 95% of vVO$_2$$_{max}$ intensity induced an attainment of ~3 and ~14% lower percentages of VO$_2$$_{max}$ at 30s of exercise compared with the 100 and 105% of vVO$_2$$_{max}$ conditions, respectively ($p<0.001$, $\eta^2=0.55$). In addition, these two latter intensities evidenced differences between themselves. Swimming at the lower intensities (95 and 100% of vVO$_2$$_{max}$) induced an achievement of ~10 and 7% lower percentages of VO$_2$$_{max}$ at 60s of exercise compared when swimming at the higher intensity ($p=0.007$, $\eta^2=0.36$).

Figure 2 shows the temporal parameters of the VO$_2$ response during the recovery period after all square-wave transition exercises performed at 95, 100 and 105% vVO$_2$$_{max}$.

During the recovery period, the time necessary to achieve 50% of VO$_2$$_{max}$ intensity ($\eta^2=0.12$) and the percentage of VO$_2$ at 30 ($\eta^2=0.02$) and 60s ($\eta^2=0.04$) time period was similar between all square-wave transition exercises ($P>0.05$).

Discussion

This study analyze the temporal aspects of the VO$_2$ response at 95, 100 and 105% of vVO$_2$$_{max}$ constant intensity with the purpose to provide appropriate work intensity for HIIT that would elicit VO$_2$$_{max}$ for well-trained swimmers. The majority of scientific knowledge within this
thematic emerged from other sports, not being presently known whether this knowledge could be
directly applied to swimming. The current main findings were that swimming at the highest
intensity (105% of vVO$_{2\text{max}}$) implies less absolute time to achieve the 90, 95 and 100% of
VO$_{2\text{max}}$ intensities, but the absolute time spent above these intensities is shorter. Moreover, the
percentage of VO$_{2\text{max}}$ corresponding to 30 and 60s of exercise is higher in the 105% of vVO$_{2\text{max}}$
intensity compared with the lower intensities. In contrast, swimming at lower intensities
(especially at 95% of vVO$_{2\text{max}}$) implies more absolute time to achieve the 90, 95 and 100% of
VO$_{2\text{max}}$ intensities, but the absolute time spent above these intensities is longer. The
cardiorespiratory response in the recovery period seems to be independent of prior exercise
intensities.

It is important to stress that different types of interval training have been investigated to
prescribe more precisely which training methods maximizes the desired cardiorespiratory fitness
adaptations in different individuals $^7$. Here, the concept that optimal improvement in
cardiorespiratory fitness is thought to occur from interval training at an intensity corresponding
from 90-100% of VO$_{2\text{max}}$ intensity $^5$ is very relevant, as well as the fact that the time spent $\geq 90$
and $\geq 95$% VO$_{2\text{max}}$ is used as a valuable criteria $^6$ and recognized as an optimal stimulus, not only
to elicit maximal cardiovascular but also to enhance peripheral adaptations $^18$. While VO$_{2\text{max}}$ is
achieved regardless of the exercise intensity within this domain, the time to achieve the VO$_{2\text{max}}$
is inversely related with exercise intensity $^19$. Therefore, the time spent above VO$_{2\text{max}}$ intensity
could vary within exercises performed at different intensities. The current study, having
analyzed three square-wave transition exercises performed at 95, 100 and 105% of vVO$_{2\text{max}}$
(within the severe and extreme exercise intensity domains) and not examining different interval
training sets, tried to gain a better understanding of the cardiorespiratory responses occurring during continuous work at this specific intensities.

In the present study, when subjects swam continuously until exhaustion at 95, 100 and 105% of vVO_{2max} intensity, they need the same relative amount of time (~25% of the Tlim total time) to achieve 90% of VO_{2max} intensity. However, the absolute time reported for the 105% of vVO_{2max} was lower as swimmers needed more ~105 and 57% of time in the 95 and 100% of vVO_{2max} intensities, respectively (η^2=0.39). Therefore, and considering the training program design throughout a macrocycle, we suggest that the higher intensities (100 and 105% of vVO_{2max}) should be applied in the general phase of the preparation training period (which purpose is to enhance the cardiorespiratory fitness), as this provides a shorter time to achieve the 90, 95 and 100% of VO_{2max} intensities, although swimmers spend less time at or above these same intensities. This latter design could also be used as an important stimulus when swimmers have at their disposal a higher fraction of time for specific HIIT in each training session, as typical in age groups.

In contrast, in the lowest intensity (95% of vVO_{2max}), the absolute time spent at intensities ≥90 of VO_{2max} intensity was almost 3- and 2-fold compared with the 105 and 100% of vVO_{2max} intensities, respectively (η^2=0.87). These general trends were also observed for the relative 95%VO_{2max} (η^2=0.38), ≥95 (η^2=0.84), 100%VO_{2max} (η^2=0.74) and ≥100 (η^2=0.75) parameters, as when subjects swam at the lower intensities (95% of vVO_{2max}) they generally needed more absolute time to achieve them but, contrarily, spent a longer absolute time at or above these intensities. Therefore, we suggest that lower intensities (95% of vVO_{2max} intensity) - as this provides a longer time spent at intensities ≥90, 95 and 100% of VO_{2max}, although swimmers need more time to achieve them - should be used in the specific phase of the
preparatory period, which aims to consolidate the cardiorespiratory adaptations gained previously in the general phase of the preparatory period. This same training design could also be used as an effective stimulus when swimmers have at their disposal a small fraction of time for specific HIIT in each training session, as typical in the master age-groups.

Although all intensities performed (95, 100 and 105% of vVO_{2max}) may be embodied as important stimulus for the cardiorespiratory fitness’s improvements, the differences reported previously in-between them could be related with VO_{2} kinetics. In fact, the slower VO_{2} kinetics at lower intensities, reflecting a slower rate at which the VO_{2} response achieves the steady state, could be a responsible mechanism. However, previous studies reported an absence of differences in time constant parameter at intensities around VO_{2max} in swimming and cycling exercises^{14,20}. Moreover, the VO_{2} values found in-between the square-wave transition exercises were similar, evidencing that if a limiting factor existed, it may be related to peripheral factors (from convective O_{2} transport, to its diffusion and utilization in the muscles) and not to central ones (O_{2} delivery and transportation to the working muscles). Other possible explanation of the differences found could be related with the Gain (ΔVO_{2}/Δwork rate) and, although this study did not analyzed it, a better metabolic adjustment’s understand within the severe intensity domain should also take it under consideration. Previous reports showed that this parameter tended to decrease with increasing intensity both in swimming and cycling exercises^{14,20,21}, being related with a higher recruitment of type II motor units (known to have a reduced relative contribution of oxidative phosphorylation^{22}). However, this fact was not supported by the lack of differences in [La^{-}]_{max} values in-between intensities in the current study. Therefore, and contrarily to time constant, the Gain seems to be a more sensitive parameter to small changes in the work rate (measured at relative percentage of the VO_{2max} intensity) and possibly be a mechanism through
which the cardiovascular system and O₂ delivery do not adjust sufficiently within the severe exercise domain.

Concomitant with the notion that a longer time is necessary to achieve the 90, 95 and 100% of VO₂max intensities at lower intensities, is the results found for the 30 and 60s time periods. The percentages of VO₂max in these latter were both lower for the 95% of vVO₂max intensity compared with the 100 and 105% of vVO₂max intensities. These time periods are largely associated with the 50 and 100m swimming freestyle efforts (respectively) and have been largely used as a work duration for HIIT interventions in both running and cycling exercises at intensities corresponding to VO₂max. The 50m effort (~30s) performed at any one of the intensities only allow the achievement between ~72 (95%vVO₂max) and 83% (105%vVO₂max) of VO₂max, revealing itself as an insufficient distance to enhance VO₂max in a single bout. In contrast, the 100m distance (~60s) seems to be a more adequate stimulus when performed at 105%vVO₂max intensity as promoted the achievement of ~95% of VO₂max. Therefore, coaches could also manipulate different intensities of vVO₂max to induce different cardiorespiratory responses at 30 and 60s work durations for HIIT intervention.

In contrast with the reported variability for the exercise phase, the recovery period seems to be independent of the intensity performed during the effort phase. Considering a possible limiting factor that a square-wave transition exercise was used for analysis, the current study suggest that the same recovery period after a specific work duration (performed between 95 and 105% of vVO₂max intensities) could be used without compromising the next set of work duration.

Further studies to establish appropriate work intensity for interval training for well-trained swimmers need to be investigated. Although the present study was delimited to male swimmers, the lack of differences reported in VO₂ kinetics, as well as in Tlim, between
well-trained male and female swimmers at maximal and supra-maximal intensities, suggests that the current results could be applied to high-level female swimmers. In addition, although the present study focused on analyzing continuous work at specific maximal and supra-maximal intensities, its conclusions could be applied when repeated intervals are performed, as it is normal during swimming training. In this latter context, the “priming effect” (elevated baseline metabolic rate – VO$_2$) during the transitions from recovery to exercise could accelerate VO$_2$ kinetics, and consequently, imply less absolute time to achieve the target intensities (90-100% of VO$_{2\text{max}}$). However, these effects appear to be linked to the elevated baseline work rate as well (passive vs. active recovery), which could dictate distinct subsequent muscle fiber recruitment profile 27.

**Practical Applications**

95% of vVO$_{2\text{max}}$ intensity stimulus should be used when coaches have at their disposal a small fraction of time for specific HIIT in each training session, as typical in master age-groups. In contrast, higher intensities stimulus (as those corresponding to 100 and 105% of vVO$_{2\text{max}}$) should be applied when there is available a higher fraction of time for specific HIIT in each training session, as typical in age groups. The 50m, the 100m distance seems to be a more adequate stimulus when performed at 105%vVO$_{2\text{max}}$ intensity, since it was the pace that allowed a higher VO$_{2\text{max}}$ intensity achieved (~ 95%).

**Conclusions**

Higher intensity - 105% of vVO$_{2\text{max}}$ -, requires less absolute time to achieve the 90, 95 and 100% of VO$_{2\text{max}}$ intensities, but the absolute time spent above these intensities is shorter, and the percentage of VO$_{2\text{max}}$ corresponding to 30 and 60s of exercise is higher compared with the
lower intensities. In contrast, swimming at lower intensities (especially 95% of vVO$_{2\text{max}}$) implies more absolute time to achieve the 90, 95 and 100% of VO$_{2\text{max}}$ intensities but the absolute time spent above these intensities is longer. The cardiorespiratory response in the recovery period seems to be independent of the prior exercise intensities.

**Acknowledgments**

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References


Figure 1. Percentage of VO$_2$ relative to VO$_{2\text{max}}$ of one subject performing the square-wave transition exercises at 105 (grey), 100 (white) and 95% (black) of vVO$_{2\text{max}}$ intensities, with the 90, 95 and 100% of VO$_{2\text{max}}$ intensities, and, 100%VO$_{2\text{max}}$, ≥100, t30 and t60 temporal parameters identified for the 95% of vVO$_{2\text{max}}$ intensity.

Figure 2. Individual (grey) and mean (black) values in the time sustained at the square-wave transition exercises released. Significant differences between intensities are identified by a and b (100 and 105% of vVO$_{2\text{max}}$, respectively) (P≤0.05).
Figure 3. Mean (± SD) of the time necessary to achieve 50% VO$_{2\text{max}}$ (50%VO$_{2\text{max}}$) and the percentages of VO$_{2\text{max}}$ at 30 and 60 s time periods (t30 and t60) during the recovery period after all square-wave transition exercises performed at 95 (black), 100 (light grey) and 105% (dark grey) of vVO$_{2\text{max}}$. 
Table 1. Mean ± SD values for the temporal parameters obtained during all square-wave transition exercises performed at 95, 100 and 105% \( \text{VO}_{2\text{max}} \) (n=12). Significant differences between intensities are identified by a and b (100% of \( \text{VO}_{2\text{max}} \) and 105% of \( \text{VO}_{2\text{max}} \), respectively) (P≤0.05).

<table>
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<th>Temporal parameters</th>
<th>Square-Wave Transition Exercises</th>
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<th>100% of ( \text{VO}_{2\text{max}} )</th>
<th>105% of ( \text{VO}_{2\text{max}} )</th>
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</tr>
<tr>
<td>100% ( \text{VO}_{2\text{max}} ) (%)</td>
<td>68.59±13.45 b</td>
<td>58.76±9.99</td>
<td>55.33±11.52</td>
<td></td>
</tr>
<tr>
<td>100% ( \text{VO}_{2\text{max}} ) (s)</td>
<td>233.75±74.34 a b</td>
<td>120.0±27.69 b</td>
<td>66.3±16.26</td>
<td></td>
</tr>
<tr>
<td>100% ( \text{VO}_{2\text{max}} ) (%)</td>
<td>47.34±16.25</td>
<td>55.41±17.78 b</td>
<td>42.08±14.05</td>
<td></td>
</tr>
<tr>
<td>100% ( \text{VO}_{2\text{max}} ) (s)</td>
<td>151.11±52.42 a b</td>
<td>95.55±29.83 b</td>
<td>58.3±19.36</td>
<td></td>
</tr>
<tr>
<td>105% ( \text{VO}_{2\text{max}} ) (%)</td>
<td>52.65±16.25 a b</td>
<td>28.24±10.53</td>
<td>34.04±11.29</td>
<td></td>
</tr>
<tr>
<td>105% ( \text{VO}_{2\text{max}} ) (s)</td>
<td>173.55±78.22 a b</td>
<td>60.0±18.20</td>
<td>44.22±13.89</td>
<td></td>
</tr>
<tr>
<td>105% ( \text{VO}_{2\text{max}} ) (%)</td>
<td>71.81±7.40 a b</td>
<td>73.8±6.62 b</td>
<td>82.64±9.44</td>
<td></td>
</tr>
<tr>
<td>105% ( \text{VO}_{2\text{max}} ) (s)</td>
<td>85.7±11.19 b</td>
<td>88.29±5.91 b</td>
<td>94.7±5.45</td>
<td></td>
</tr>
</tbody>
</table>

90, 100 and 105% \( \text{VO}_{2\text{max}} \) = percentage of \( \text{Tlim} \) spent to attain 90, 100 and 105% \( \text{VO}_{2\text{max}} \), respectively; ≥90, 100 and 105 = time of \( \text{Tlim} \) spent at intensities ≥90, 100 and 105%\( \text{VO}_{2\text{max}} \), respectively; t30 and t60 = percentages of \( \text{VO}_{2\text{max}} \) at 30 and 60 s time periods, respectively.