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VO_2 at Maximal and Supramaximal Intensities: Lessons to High-Intensity Interval Training in Swimming

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Purpose: To establish appropriate work intensity for interval training that would elicit maximal oxygen uptake (VO_2max) for well-trained swimmers. ***Methods:*** Twelve male competitive swimmers completed an incremental protocol to determine the minimum velocity at VO_2max (vVO_2max) and, in randomized order, 3 square-wave exercises from rest to 95%, 100%, and 105% of vVO_2max. Temporal aspects of the VO_2 response were examined in these latter. ***Results:*** Swimming at 105% of vVO_2max took less ($P < .04$) absolute time to achieve 90%, 95%, and 100% of VO_2max 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_2max. However, swimming at 95% of vVO_2max resulted in longer absolute time ($P < .001$) at or above the desired intensities (90%: 268.3 ± 72.5 s; 95%: 233.8 ± 74.3 s; 100%: 173.6 ± 78.2 s) and more relative time at or above 95% of VO_2max than 105% of vVO_2max (68.6% ± 13.5% vs 55.3% ± 11.5%, $P < .03$), and at or above 100% of VO_2max than 100% and 105% of vVO_2max (52.7% ± 16.3% vs 28.2% ± 10.5% and 34.0% ± 11.3%, $P < .001$). At 60 s of effort, swimmers achieved 85.8% ± 11.2%, 88.3% ± 5.9%, and 94.7% ± 5.5% of the VO_2max when swimming at 95%, 100%, and 105% of vVO_2max, respectively. ***Conclusions:*** When training to elicit VO_2max, 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 60-s time period seem to be a more adequate stimulus than shorter ones (~30-s), especially when performed at 105% of vVO_2max intensity.

Keywords: cardiovascular responses, exercise, recovery, severe and extreme intensities

Interval training was first described by Reindell and Roskamm and popularized in the 1950s by 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 (ie, 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 means 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% to 100% VO_2max,[5] where the time spent ≥90% and ≥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 (eg, 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 in order to provide greater improvement in aerobic fitness.[6] This prescription method underlines that the most adequate duration in intermittent runs at vVO_2max was one-half of time to exhaustion (Tlim). Based on that, Billat et al[12] showed improvements in the VO_2max and the vVO_2max in trained runners after only 4 weeks. Considering the reports of similar Tlim at vVO_2max intensity among different exercises modes, where swimming was one of the modes considered,[9,13] may suggest that work duration at vVO_2max 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_2max for well-trained swimmers, by examining the temporal aspects of the VO_2 response at 95%, 100%, and 105% vVO_2max constant intensity.

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Methods

Subjects

Twelve national-level competitor male swimmers (mean ± SD age 18.2 ± 4.1 y, height 1.79 ± 0.65 m 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 8 times per week and had been regularly involved in competitive events at a national level for at least 3 years. All participants (or parents/guardians when subjects were under 18 y) provided informed written consent, and subjects avoided strenuous exercise in the 24 hours 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 hours before testing. The institutional ethical review board approved the study design, which was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki.

Design

The protocol involved 4 visits to the swimming pool facilities over a 2-week period. In the first session, each swimmer performed an individualized, intermittent, incremental protocol for front-crawl VO_2max and $v$$VO_2$max assessment, with increments of 0.05 m/s and 30-s rest intervals between each 200-m stage until exhaustion, with initial velocity set at the individual's performance on the 400-m freestyle, followed by 7 increments of velocity.[14] The velocity was controlled at each stage by a visual pacer with flashing lights in the bottom of the pool (TAR.1.1, GBK electronics, Aveiro, Portugal). For visits 2 to 4, subjects performed a single square-wave transition exercise from rest to different percentages of VO_2max velocity (95%, 100%, and 105%) to volitional exhaustion, which were presented in random order. This test consisted of 3 distinct phases: 10-minute warm-up exercise at 50% of the $v$$VO_2$max, 5-minute recovery, and the maintenance of the different percentages of VO_2max 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. 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 (K4b^2, Cosmed, Rome, Italy) that was suspended over the water (at a 2-m height) in a steel cable, following the swimmer along the pool, which minimized 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 et al[15]). The gas analyzer was calibrated before each test with gasses of known concentration (16% O_2 and 5% CO_2) and the turbine volume transducer was calibrated with a 3-L syringe following a standard certified commercial gas preparation ("K4b^2 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 30s intervals (intermittent incremental protocol) and immediately at the end of exercise at minutes 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).

VO_2max 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 seconds of the exercise in both protocols.

Data Analysis

First, occasional VO_2 breath values were omitted from the analysis (caused by swallowing, coughing, sighing, signal interruptions, etc) by including only those between VO_2 mean ± SD. After verification of the data, individual breath-by-breath VO_2 responses were smoothed by using a 3-breath moving average and time average of 5 seconds, using the time-averaging function of the Cosmed analysis software (Cosmed, Rome, Italy).[17]

The temporal parameters of the VO_2 response during all square-wave transition exercises considered were the percentage of Tlim spent to attain 90%, 95%, and 100% VO_2max (90% VO_2max, 95% VO_2max, and 100% VO_2max, respectively); the time of Tlim spent at intensities ≥90%VO_2max (≥90), ≥95%VO_2max (≥95), and ≥100%VO_2max (≥100); and the percentage of VO_2max at 30-second time period (t30) and at 60-second time period (t60). The VO_2 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% VO_2max (50%VO_2max) and t30 and t60. A representative VO_2 kinetics curve with the temporal parameters measures is shown in Figure 1.

Statistical Analysis

Shapiro-Wilk tests 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 $v$$VO_2$max 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 (η^2) were determined against the following criteria: small, 0.2 to 0.5; moderate, 0.5 to 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 are shown in Figure 2.

The mean VO_2 values for the incremental protocol and square-wave transition exercises were similar (η^2 = .15), although the different intensity had an effect on the mean [La]max values (P = .006, η^2 = .31) since they were ~16% and ~8% higher in 100% and 105% $v$$VO_2$max tests, respectively, compared with the incremental protocol. As expected, the work intensity had an effect on the mean Tlim values (P < .001, η^2 = .69), which were ~18% and ~43% (η^2 = .80) higher at 95% of $v$$VO_2$max compared with 100% and 105% tests, respectively.

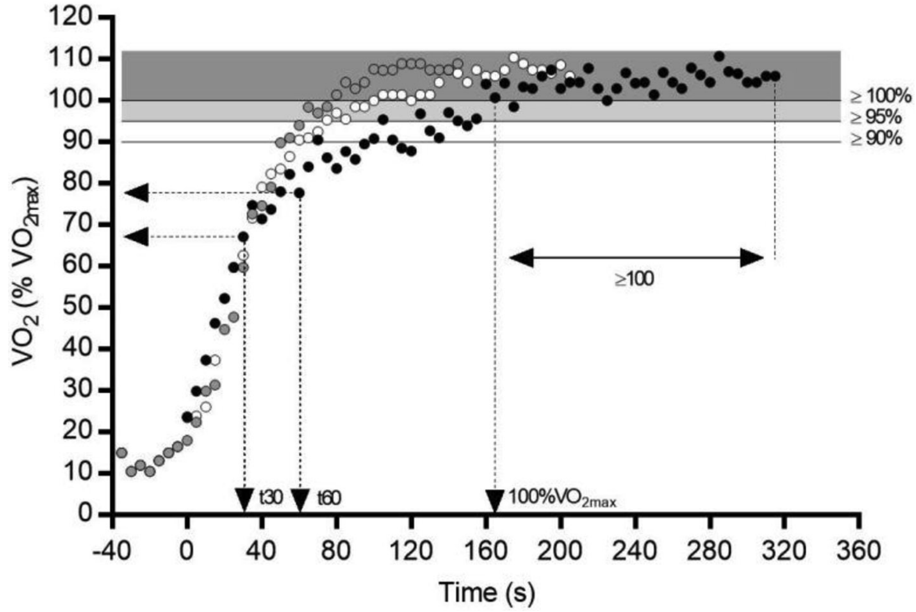

Figure 1 — Percentage of VO_2 relative to VO_2max of 1 subject performing the square-wave transition exercises at 105% (gray), 100% (white), and 95% (black) of vVO_2max intensities, with the 90%, 95%, and 100% of VO_2max intensities, and 100% VO_2max, ≥100, t30 (30-s time period), and t60 (60-s time period) temporal parameters identified for the 95% of vVO_2max intensity.

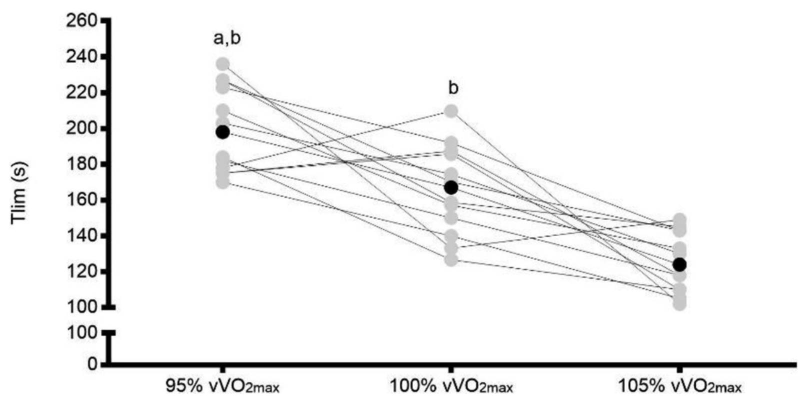

Figure 2 — Individual (gray) and mean (black) values in the time sustained at the square-wave transition exercises released. Significant differences between intensities are identified by superscript letters (100% and 105% of vVO_2max, respectively) ($P \leq .05$).

Table 1 shows the temporal parameters of the VO_2 response during the square-wave transition exercises performed at 95%, 100%, and 105% vVO_2max.

In the 90%VO_2max parameter, the absolute time was ~105% and ~57% lower in the 95% and 100% of vVO_2max intensities, respectively, compared with the highest intensity ($P = .004$, $\eta^2 = .39$). This trend was also observed for the absolute ≥90 parameter, which was higher in the 95% and 100% of vVO_2max intensities compared with 105% of vVO_2max ($P < .001$, $\eta^2 = .87$). In addition, these 2 intensities evidenced differences between themselves.

The 95%VO_2max relative and absolute parameter was ~23% lower ($P = .02$, $\eta^2 = .30$) and ~84% higher ($P = .005$, $\eta^2 = .38$) for the 95% of vVO_2max compared with 105% of vVO_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_2max needed less time to achieve the 95%VO_2max intensity compared with 95% and 100% of vVO_2max ($P < .001$, $\eta^2 = .84$). In addition, these 2 latter intensities evidenced differences between themselves.

To achieve the 100% VO_2max intensity, subjects needed ~37% more of the Tlim total time at 100% of vVO_2max compared with 105% of vVO_2max intensity ($P = .04$, $\eta^2 = .18$). However, when absolute values were considered, 95% of vVO_2max was the intensity that needed more time to achieve 100% VO_2max compared with 100% and 105% of vVO_2max intensities ($P < .001$, $\eta^2 = .74$). In addition, these 2 latter intensities evidenced differences between themselves. The ≥100 parameter was ~87% and ~58% higher in the 95% of vVO_2max compared with 100% and 105% of vVO_2max intensities, respectively ($P < .001$, $\eta^2 = .54$). This same trend was observed for the absolute values ($P < .001$, $\eta^2 = .75$).

Table 1 Temporal Parameters Obtained During All Square-Wave Transition Exercises Performed at 95%, 100%, and 105% vVO_2max (N = 12), Mean ± SD

		Square-Wave Transition Exercises		
Temporal parameter		**95% of vVO_2max**	**100% of vVO_2max**	**105% of vVO_2max**
90% VO_2max	(%)	22.05 ± 11.60	28.50 ± 7.64	27.26 ± 6.27
	(s)	72.08 ± 34.34^{b}	55.83 ± 24.47^{b}	35.0 ± 7.68
≥90	(%)	77.94 ± 11.60	71.50 ± 7.64	72.73 ± 6.27
	(s)	268.33 ± 72.50^{a,b}	148.33 ± 22.46^{b}	89.66 ± 15.97
95% VO_2max	(%)	31.41 ± 13.45^{b}	41.23 ± 9.99	44.66 ± 11.52
	(s)	106.66 ± 43.91^{b}	84.16 ± 35.40	58.33 ± 15.85
≥95	(%)	68.59 ± 13.45^{b}	58.76 ± 9.99	55.33 ± 11.52
	(s)	233.75 ± 74.34^{a,b}	120.0 ± 27.69^{b}	66.33 ± 16.26
100% VO_2max	(%)	47.34 ± 16.25	55.41 ± 17.78^{b}	42.08 ± 14.05
	(s)	151.11 ± 52.42^{a,b}	95.55 ± 29.83^{b}	58.33 ± 19.36
≥100	(%)	52.65 ± 16.25^{a,b}	28.24 ± 10.53	34.04 ± 11.29
	(s)	173.55 ± 78.22^{a,b}	60.0 ± 18.20	44.22 ± 13.89
t30	(%)	71.81 ± 7.40^{a,b}	73.83 ± 6.62^{b}	82.64 ± 9.44
t60	(%)	85.76 ± 11.19^{b}	88.29 ± 5.91^{b}	94.70 ± 5.45

Note: Significant differences between intensities are identified by superscript a and b (100% of vVO_2max and 105% of vVO_2max, respectively) ($P \leq .05$). 90%, 100%, and 105%VO_2max = percentage of Tlim spent to attain 90%, 100%, and 105% VO_2max, respectively; ≥90, 100, and 105 = time of Tlim spent at intensities ≥9%0, 100%, and 105%VO_2max, respectively; t30 and t60 = percentages of VO_2max at 30- and 60-s time periods, respectively.

Swimming at 95% of vVO_2max intensity induced an attainment of ~3% and ~14% lower percentages of VO_2max at 30 seconds of exercise compared with 100% and 105% of vVO_2max conditions, respectively ($P < .001$, $\eta^2 = .55$). In addition, these 2 latter intensities evidenced differences between themselves. Swimming at the lower intensities (95% and 100% of vVO_2max) induced an achievement of ~10% and 7% lower percentages of VO_2max at 60 seconds of exercise compared when swimming at the higher intensity ($P = .007$, $\eta^2 = .36$).

Figure 3 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_2max.

During the recovery period, the time necessary to achieve 50% of VO_2max intensity ($\eta^2 = .12$) and the percentage of VO_2 at the 30-second ($\eta^2 = .02$) and 60s ($\eta^2 = .04$) time period was similar between all square-wave transition exercises ($P > .05$).

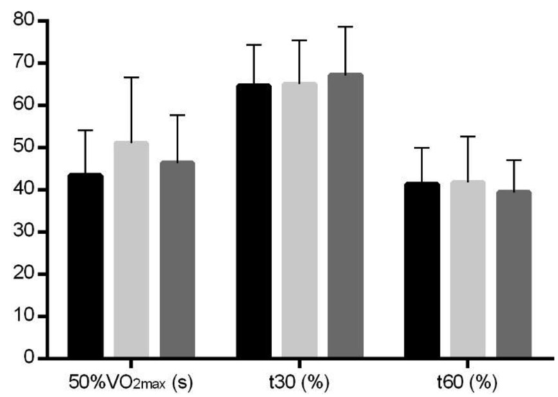

Figure 3 — Mean (± SD) of the time necessary to achieve 50% VO_2max (50% VO_2max) and the percentages of VO_2max at 30-second and 60-second time periods (t30 and t60) during the recovery period after all square-wave transition exercises performed at 95% (black), 100% (light gray), and 105% (dark gray) of vVO_2max.

Discussion

This study analyzed the temporal aspects of the VO_2 response at 95%, 100%, and 105% of vVO_2max constant intensity with the purpose to provide appropriate work intensity for HIIT that would elicit VO_2max for well-trained swimmers. The majority of scientific knowledge in 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_2max) implies less absolute time to achieve 90%, 95%, and 100% of VO_2max intensities, but the absolute time spent above these intensities is shorter. Moreover, the percentage of VO_2max corresponding to 30s and 60s of exercise is higher in the 105% of vVO_2max intensity compared with the lower intensities. In contrast, swimming at lower intensities (especially at 95% of vVO_2max) implies more absolute time to achieve 90%, 95%, and 100% of VO_2max 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 maximize 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% to 100% of VO_2max intensity[5] is very relevant, as well as the fact that the time spent ≥90% and ≥95%

VO_2max 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_2max is achieved regardless of the exercise intensity within this domain, the time to achieve VO_2max is inversely related with exercise intensity.[19] Therefore, the time spent above VO_2max intensity could vary within exercises performed at different intensities. The current study, having analyzed 3 square-wave transition exercises performed at 95%, 100%, and 105% of $v$$VO_2$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 these specific intensities.

In the current study, when subjects swam continuously until exhaustion at 95%, 100%, and 105% of $v$$VO_2$max intensity, they needed the same relative amount of time (~25% of the Tlim total time) to achieve 90% of VO_2max intensity. However, the absolute time reported for 105% of $v$$VO_2$max was lower as swimmers needed more ~105% and 57% of time in the 95% and 100% of $v$$VO_2$max intensities, respectively ($\eta^2 = .39$). Therefore, and considering the training program design throughout a macrocycle, we suggest that the higher intensities (100% and 105% of $v$$VO_2$max) should be applied in the general phase of the preparation training period (the purpose of which 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 $v$$VO_2$max), the absolute time spent at intensities ≥90% of VO_2max intensity was almost 3- and 2-fold compared with the 105% and 100% of $v$$VO_2$max intensities, respectively ($\eta^2 = .87$). These general trends were also observed for the relative 95%VO_2max ($\eta^2 = .38$), ≥95 ($\eta^2 = .84$), 100%VO_2max ($\eta^2 = .74$), and ≥100 ($\eta^2 = .75$) parameters, as when subjects swam at the lower intensities (95% of $v$$VO_2$max) they generally needed more absolute time to achieve them but, contrarily, spent a longer absolute time at or above these intensities. Therefore, we suggest that lower intensities (95% of $v$$VO_2$max 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 $v$$VO_2$max) may be embodied as important stimulus for the cardiorespiratory fitness's improvements, the differences reported previously in-between them could be related with VO_2 kinetics. In fact, the slower VO_2 kinetics at lower intensities, reflecting a slower rate at which the VO_2 response achieves the steady state, could be a responsible mechanism. However, previous studies reported an absence of differences in time constant parameter at intensities around VO_2max in swimming and cycling exercises.[14,20] Moreover, the VO_2 values found in-between the square-wave transition exercises were similar, evidencing that if a limiting factor existed, it may be related to peripheral factors (from convective O_2 transport, to its diffusion and utilization in the muscles) and not to central ones (O_2 delivery and transportation to the working muscles). Other possible explanations of the differences found could be related with the Gain ($\Delta VO_2/\Delta$work rate) and, although this study did not analyze it, a better metabolic adjustment 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 a mechanism through which the cardiovascular system and O_2 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% VO_2max intensities at lower intensities, is the results found for the 30-second and 60-second time periods. The percentages of VO_2max in these latter were both lower for the 95% $v$$VO_2$max intensity compared with the 100% and 105% $v$$VO_2$max intensities. These time periods are largely associated with the 50-m and 100-m swimming freestyle efforts, respectively,[23] and have been largely used as a work duration for HIIT interventions in both running[24] and cycling[8] exercises at intensities corresponding to VO_2max. The 50-m effort (~30 s) performed at any one of the intensities only allowed an achievement between ~72% (95%$v$$VO_2$max) and 83% (105%$v$$VO_2$max) of VO_2max, revealing itself as an insufficient distance to enhance VO_2max in a single bout. In contrast, the 100-m distance (~60 s) seems to be a more adequate stimulus when performed at 105% $v$$VO_2$max intensity as promoted the achievement of ~95% VO_2max. Therefore, coaches could also manipulate different intensities of $v$$VO_2$max to induce different cardiorespiratory responses at 30-second and 60-second 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 suggests that the same recovery period after a specific work duration (performed between 95% and 105% $v$$VO_2$max 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 current study was delimited to male swimmers, the lack of differences reported in VO_2 kinetics,[25] as well as in Tlim,[26] between well-trained male and female swimmers at maximal and supramaximal intensities, suggests that the current results could be applied to high-level female swimmers. In addition, although the current study focused on analyzing continuous work at specific maximal and supramaximal 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_2max). 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

Ninety-five percent of $v$$VO_2$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 $v\text{VO}_2$max) should be applied when a higher fraction of time is available for specific HIIT in each training session, as typical in age groups. In contrast to the 50-m, the 100-m distance seems to be a more adequate stimulus when performed at 105%$v\text{VO}_2$max intensity, since it was the pace that allowed a higher VO_2max intensity to be achieved (~95%).

Conclusions

Higher intensity—105% of $v\text{VO}_2$max—requires less absolute time to achieve the 90%, 95%, and 100% VO_2max intensities, but the absolute time spent above these intensities is shorter, and the percentage of VO_2max corresponding to 30s and 60s of exercise is higher compared with the lower intensities. In contrast, swimming at lower intensities (especially 95% of $v\text{VO}_2$max) implies more absolute time to achieve the 90%, 95%, and 100% of VO_2max 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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