Physiological responses during interval training at relative to critical velocity intensity in young swimmers

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Abstract

Objectives: The purpose of this study was to examine the physiological responses on three interval training sets performed at intensities relative to the critical velocity which was calculated from two different combinations of distances using a 2-parameter linear model.

Methods: In a controlled repeated measures design, ten male well trained swimmers (age: 15.2 ± 1.2 years) swam 5 × 400-m, 10 × 200-m and 20 × 100-m on separate days with rest to swimming ratio 1:8, aiming to maintain the critical velocity calculated from distances of 50, 100, 200, 400-m (CV4) or 200, 400-m (CV200–400). Results: The sustained velocity on the 5 × 400-m was lower compared to CV4 and velocity on the 20 × 100-m was higher compared to CV200–400. The velocity on the 10 × 200-m was kept similar to both CV4 and CV200–400 (5 × 400-m: 1.27 ± 0.07 vs. CV4: 1.33 ± 0.09 m s\(^{-1}\), \(p < 0.05\); 20 × 100-m: 1.32 ± 0.02 vs. CV200–400: 1.28 ± 0.09 m s\(^{-1}\), \(p < 0.05\); 10 × 200-m: 1.30 ± 0.10 m s\(^{-1}\) vs. CV4 and CV200–400, \(p > 0.05\)). The blood lactate concentration increased after 1200 compared to 400-m (4.45 ± 0.23 vs. 5.82 ± 0.24 mmol l\(^{-1}\), \(p < 0.05\)) and was no different between sets (\(p > 0.05\)). Stroke rate and stroke length were not different between and within conditions (\(p > 0.05\)). Heart rate during the recovery periods was lower in the 5 × 400-m compared to 10 × 200-m and 20 × 100-m training set (\(p < 0.05\)).

Conclusion: Interval swimming pace can be adjusted in relation to critical velocity calculated from distances of 200 and 400-m or from distance of 50, 100, 200, 400 m. When the distance of repetitions is increased from 100 to 200 and 400-m the velocity should be reduced by 2% to achieve similar metabolic responses.

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1. Introduction

The application of a reliable test is required in order to evaluate swimming capacities and delimitate the interval swimming training pace.¹ The slope of distance vs. time relationship which is defined as the critical swimming velocity (CV) is accepted as a valid index for the evaluation of aerobic endurance capacity of swimmers.¹–³ Furthermore, it has been suggested that CV can be used for the design and control of pace during interval swimming training.³ A prerequisite for the use of CV pace for training prescription is to locate it across the exercise intensity domains. Although this question is still under research for swimmers, it seems that swimming at the CV calculated by distances of 100–800 m is located within the severe exercise intensity domain (i.e. above the maximum lactate steady state; MLSS).⁴ This is because continuous swimming at this velocity causes exhaustion in less than 25 min, while it progressively increases blood lactate values and oxygen uptake responses near VO₂max.³ However, intermittent swimming at the velocity corresponding to CV (10 × 400-m, 4 × 400-m, 5 × 400-m) can be sustained for a long period with a steady,¹–⁶ or increasing⁷,⁸ blood lactate concentration. In the above mentioned studies the combination of distances used for the CV determination was not the same and this may have caused over-estimation or under-estimation on the prescribed velocity.¹,⁴,⁶,⁷ In addition, a significant change or no difference on the evolution...
of stroke mechanics during a training set of repetitions has been reported,7,8 whereas repetitions of 400-m distance have been used to examine the sustainability of the CV velocity in previous studies.5–7 Using shorter (i.e. 100, 200-m) compared to longer (400-m) distance repetitions an increased sustained velocity is expected, despite similar metabolic responses after the training set.9 The sustained velocity may also increase by extending the resting interval,9 and changes in the interval duration at the same intensity may alter the energy system contribution.10,11 It is interesting and of practical value to examine the physiological responses during interval training sets around the CV intensity using repetitions of distances that have been previously suggested for aerobic endurance improvement of swimmers, such as 200 or 100-m.12 The purpose of this study was to compare the physiological responses, stroke parameters changes and the ability to sustain a velocity relative to CV calculated from two different combinations of distances during interval training sets using repetitions of 100, 200 and 400-m.

2. Methods

Ten male swimmers (age: 15.2 ± 1.2 years, body mass: 67.5 ± 7.3 kg, height: 1.72 ± 0.04 m) participated in the study. All swimmers were trained for 1 h and 45 min to 2 h daily participating in six–nine training sessions per week, covering distances of 4000–5000 m per day (30,000–42,000 m per week). The swimmers were specialized in various swimming techniques and competitive distances and their best 200-m freestyle record corresponded to 81 ± 5% of the present youth world record and 462 ± 76 FINA points for a 50-m pool (Supplemental file 1). The swimmers and their parents were informed in detail about the experimental risks and procedures and signed an informed consent document prior to the investigation, which was completed eight to twelve weeks prior to the national age-group championship. The investigation was approved by the Institutional Review Board for use of Human subjects according to the Helsinki declaration.

Within four consecutive days all swimmers performed all-out efforts over distances of 50, 100, 200, 400-m after a standard warm-up (400-m self-paced swim–200-m leg kick–200-m arm-pull, 4 × 50-m progressively increasing intensity, 2 × 10-m sprints, 100-m cool-down). The all-out efforts were performed in a counterbalanced order and started from the blocks. The critical velocity was calculated using all four distances (CV4) and using distances of 200 and 400-m (CV200–400).2,5 Following the CV4 and CV200–400 calculation, the swimmers completed three different experimental conditions in a controlled repeated measures design. In each experimental condition one of the following interval training sets (total distance of 2000-m for each set) was applied: (i) five repetitions of 400-m (5 × 400-m), (ii) ten repetitions of 200-m (10 × 200-m), (iii) twenty repetitions of 100-m (20 × 100-m). The order of experimental conditions was counterbalanced for nine swimmers and was randomly assigned for the tenth swimmer. The interval training sets were performed a week apart and were completed within a period of 15–20 days for each swimmer. The interval duration was individually adjusted based on the duration of the first repetition, applying a rest to swimming ratio 1:8 and was kept the same during successive repetitions of each set. The swimmers were instructed for their pace and were encouraged to maintain a velocity corresponding to CV4 keeping their head at the level of one of the experimenters who was walking along the side of the swimming pool. The experimenter adjusted the required pace while looking at a digital chronograph. In case a swimmer was not able to follow the CV4 pace, he was strongly encouraged to increase the pace but was not stopped if he was able to keep swimming at least with the CV200–400 pace. The time to cover each repetition and the corresponding interval duration were recorded by an experienced time-keeper using a digital chronograph (Casio, HS 1000, Japan).

A finger-tip blood sample was taken at rest and every 400-m for the determination of lactate concentration (Accutrend Lactate, Hoffmann-La Roche Ltd., Basel, Switzerland). The interval duration after the second, fourth, and eighth repetition on the 10 × 200-m and the fourth, eighth, twelfth and sixteenth repetition on the 20 × 100-m were slightly extended (20–30 s) for blood sampling. Heart rate was recorded continuously in each trial (Polar S810i). The time to complete 3 stroke cycles (T3) was recorded every second 50-m split and was used to calculate the stroke rate (SR = 180·T3−1). Stroke length (SL) was calculated from swimming velocity (V) and stroke rate (SL = V·SR−1). The mean SR and SL of each 400-m in each set were used for comparison. The rate of whole body perceived exertion (RPE) was recorded every 400-m using a 10-point scale.13 All tests were performed in a 50-m outdoor swimming pool with a water temperature of 26–27 °C and 5 min after a warm-up typically used before a training session (800 m easy self-paced swimming at intensity below 150 b min−1, 4 × 50 m progressively increasing intensity). Two days before each experimental condition the same low intensity and volume of training was applied. The swimmers recorded their nutrition two days before the first experimental condition and followed the same diet before each subsequent condition. All tests were conducted during the same time of the day (±1 h).

The average velocity, SR and SL of each 400-m repetition were used in the statistical analysis. Normal distribution of the data was tested using the Kolmogorov–Smirnov test and sphericity was verified by the Mauchly’s test. A Two-way analysis of variance for repeated measures on both factors (3 training sets × repetitions) was used for the statistical analysis of blood lactate, heart rate and stroke parameters (SR and SL). One-way analysis of variance for repeated measures was used for the comparison of the average velocity in each training set with CV4 and CV200–400. The Tukey post hoc test was used to locate possible differences between
3. Results

The duration of swimming was longer during the 5 × 400-m compared to the 10 × 200-m and 20 × 100-m (26.3 ± 1.3 vs. 25.8 ± 2.0 and 25.3 ± 1.7 min, p < 0.05) and the total interval time was different between conditions (5 × 400-m: 2.6 ± 0.1 vs. 10 × 200-m: 2.9 ± 0.2 vs. 20 × 100-m: 3.0 ± 0.2 min, p < 0.05). However, the summary of swimming time plus the interval, including the additional time to complete the five blood samplings, was similar between conditions (5 × 400-m: 29.6 ± 1.6, 10 × 200-m: 29.3 ± 2.2, 20 × 100-m: 29.5 ± 1.9 min, p > 0.05).

The mean swimming velocity of the 5 × 400-m was lower compared to CV4 (96 ± 2% of the CV4; ES = 0.64, P = 1, p < 0.05). Velocities during the 10 × 200-m and 20 × 100-m were similar and no different compared to CV4 (98 ± 2% and 100 ± 3% of CV4; ES = 0.29, p > 0.05). CV200–400 was lower compared to CV4 and 20 × 100-m but no different compared to 5 × 400-m and 10 × 200-m training sets (ES = 0.54, P = 1, p < 0.05; Fig. 1A, p < 0.05). The mean velocity during the 5 × 400-m, 10 × 200-m, and 20 × 100-m training sets corresponded to 99 ± 3%, 102 ± 3, 103 ± 4% of the CV200–400. Swimming velocity was maintained constant within each set of repetitions (p > 0.05) but was slower in each 400-m repetition of the 5 × 400-m compared to CV4 and to 20 × 100-m (Fig. 1B, p < 0.05). The velocity of the repetitions five to twelve in the 20 × 100-m set was faster compared to CV200–400 (Fig. 1B, p < 0.05). The CV4, CV200–400 and the
Fig. 2. Blood lactate concentration during the training sets of 5 × 400-m, 10 × 200-m and 20 × 100-m repetitions. \( p < 0.05 \) compared to the first 400-m. All values are mean ± SD.

5 × 400-m, 10 × 200-m, 20 × 100-m velocities corresponded to 97 ± 1, 93 ± 2, 93 ± 2, 95 ± 2, 97 ± 2% of the 400-m velocity respectively (1.37 ± 0.09 m s\(^{-1}\)).

The blood lactate concentration was not different between conditions \((p > 0.05)\). Pooled data from all three conditions showed that blood lactate concentration was increased after 1200-m compared to 400-m (4.45 ± 1.1 vs. 5.82 ± 1.3 mmol l\(^{-1}\), \(ES = 1.02, p < 0.05, \) Fig. 2). Blood sampling at 800-m was completed at approximately the 12th min during the training sets and was no different with blood lactate values measured at the 30th min of the training set (pooled data, 5.25 ± 1.13 vs. 6.24 ± 1.13 mmol l\(^{-1}\), \(ES = 0.87, p > 0.05\)). Inspection of the individual blood lactate responses showed that six swimmers in the 5 × 400-m \((ES = 1.25)\), three swimmers in the 10 × 200-m \((ES = 0.39)\) and five swimmers in the 20 × 100-m \((ES = 0.85)\) increased the lactate concentration more than one mmol l\(^{-1}\) between 800 and 2000-m (between 12th and 30th min). Heart rate during swimming was similar between conditions (188–192 b min\(^{-1}\), \(p > 0.05\)) but lower in the 5 × 400-m compared to 10 × 200-m and 20 × 100-m conditions during the recovery periods \((p < 0.05, \) Table 1). No differences were observed on SR and SL across conditions and repetitions \((p > 0.05, \) Table 1). The RPE was no different between conditions but was increased significantly after 1200-m compared to 400-m \((p < 0.05, \) Table 1). The 400-m time was related to CV\(_4\) and CV\(_{200–400}\) \((r = 0.99, r = 0.96, p < 0.05)\).

4. Discussion

The findings of the present study show that during a training set of 5 × 400-m repetitions the swimmers cannot maintain the velocity corresponding to critical velocity calculated by the distances of 50, 100, 200, 400 m (CV\(_4\)). In contrast, the critical velocity calculated from distances of 200 and 400-m (CV\(_{200–400}\)) can be sustained during the same set of repetitions. The CV\(_4\) can be sustained when using 100 or 200-m repetitions and applying a rest to swimming ratio of 1:8. Half of the swimmers showed increases on blood lactate concentration more than 1 mmol l\(^{-1}\) between min 12 and 30 in the 5 × 400-m and 20 × 100-m conditions while maintaining SR and SL.

The ability to sustain a prescribed velocity is probably attributed to the internal perception of the intensity of the exercise. It has been reported that experienced swimmers may freely choose a pace similar to the maximum lactate steady state during a long duration effort (i.e. 2000-m). Swimmers in the present study probably perceived the CV\(_4\) intensity as non-sustainable for the 5 × 400-m repetitions selecting a pace by 4% lower. This indirectly may imply that CV\(_4\) intensity does not correspond to a metabolically steady state. In support to the present findings, the swimmers in previous studies were able to sustain velocity 5% below CV for 49 min with steady oxygen uptake and lactate responses (3–5 mmol l\(^{-1}\)) during continuous and interval swimming. The duration of each 400-m repetition was about 5–6 min. Exercise duration of 4–6 min compared to 1 min (6 × 4 and 4 × 6-min vs. 24 × 1-min), resulted in a higher VO\(_2\) and heart rate during interval running forcing the runners to adjust their pace to a lower intensity. Similarly, swimmers increased their velocity in the shorter distances of 24 × 100 vs. 6 × 400-m, and even more with a longer rest interval when they were asked to maintain a pace corresponding to a blood lactate concentration of 4 mmol l\(^{-1}\).

In contrast to 5 × 400-m the velocity corresponding to CV\(_4\) was sustained during the 10 × 200-m and 10 × 200-m repetitions. It is likely that the 2% and 4% higher intensity during 10 × 200-m and 20 × 100-m resulted in a faster but similar increase in oxygen uptake in each repetition compared to 5 × 400-m which was perceived as sustainable because of the shorter duration of each effort. It should not be overlooked that the total swimming time was longer in the 5 × 400-m and the total rest interval duration was longer in the 10 × 200-m and 20 × 100-m conditions. Although the rest interval duration does not seem to affect the sustained velocity and physiological responses during 4-min running bouts, the duration of exercise may affect the time required to maintain a high percentage of VO\(_2\)max, increasing the perception of effort in swimmers and runners during high intensity intermittent exercise. It is interesting that swimmers in the present study adopted the pace from the first repetition of each set. They are probably adapted in adjusting to steady physiological stress because they follow similar interval sets during daily training. This is probably the result of a progressively increasing but non-maximal perception of effort (end-RPE values 7–8) at all training sets which is in agreement with previous studies using similar interval protocols. Therefore, the duration of each exercise bout and the number of repetitions may dictate the pace selection.
Knowledge concerning the location of the CV across the exercise intensity domains would have helped us to explain our findings. Despite recent efforts, this has not been resolved while a main concern is the selection of appropriate swimming distances for the calculation of CV. Several combinations of distances and number of all-out efforts ranged from 50 to 2000 m have been used. Using CV for the evaluation of the aerobic endurance, scientists should assure the balance of several assumptions with a practical, time saving and easily applicable in populous groups procedure. Longer duration all-out efforts such as those used in previous studies (i.e. 800, 2000 m; ~10–30 min) may not adequately motivate the young swimmers. In this case shorter distances (50–400 m) may be used, although the resulted CV4 may correspond to a different intensity domain. Based on the present results CV200–400 may be more appropriately used for longer repetitions (i.e. n × 400-m), while the CV4 may be more appropriately used for short distance repetitions (i.e. n × 100-m) during interval swimming training. To extend this observation it seems that CV4 and CV200–400 may not represent the same intensity, although they may be located within the same intensity domain. It is likely that CV4 may be located close to the upper limit, while CV200–400 may be located in the lower limit of the severe domain. This information has practical importance for coaches helping them in the interval training planning for the improvement of aerobic endurance.

The blood lactate concentration was increased after 1200 compared to 400-m in all conditions without any further changes. Despite no statistical differences in blood lactate response after 800 compared to 2000-m the magnitude of the effect size of the pooled values was notable (ES = 0.87) and half of the swimmers showed increased blood lactate by more than one mmol L\(^{-1}\) during the 5 × 400-m and the 20 × 100-m conditions. A lower increase (ES = 0.39, 0.6 mmol L\(^{-1}\)) was observed in the 10 × 200-m condition (Fig. 2). In a previous study the average lactate response on 24 × 100-m, 12 × 200-m or 6 × 400-m training sets was similar despite the differences in the rest interval duration (10 vs. 30 s) and the sustained velocity by 1–3%. Despite similar blood lactate values, the kinetics of other physiological parameters should be examined during the exercise and these may be useful in characterising the metabolic stress of the interval training. Although such data are not available for swimmers, there is evidence that running and cycling interval training protocols may not simulate those of swimming but it is likely that the young well trained swimmers were able to adjust their pace at a given distance or rest interval in order to avoid a severe metabolic response, thus swimming in the sustainable heavy intensity domain.

It is interesting to note the maintenance of stable SR and SL in all conditions in the present study (Table 1). Maintenance of technical characteristics is important for young swimmers and this was succeeded despite the high intensity of these sets. The present observation is in agreement with previous findings during interval swimming. However, a decrease of SL at a velocity corresponding to 87% of the maximum aerobic speed, as well as in SR during intermittent swimming have been reported. It was possibly not necessary for the swimmers in the present study to change
their SR and SL since they were keeping the pace they felt able to sustain. A substantial increase in SR and a reduction of SL have been reported at velocities above the CV.22,23 Whatever the case, the maintenance of a stable SR and SL indicate that no significant deterioration in technical parameters occurred during all three conditions. This implies that the interval swims investigated in the present study are appropriate for the establishment of efficient swimming technique in young swimmers and this should be considered by coaches.

5. Conclusion

Critical velocity can be effectively used for the design of interval swimming training sets. The metabolic and stroke mechanics responses during these sets indicate that they can be used for the improvement of aerobic endurance. Despite non-steady metabolic responses, repetitions of distances of 100, 200 and 400-m can be used during interval training with an exercise to rest ratio of 1:8. However, appropriate adjustment of the swimming pace should be applied according to the set distance and the distances used for the calculation of CV.

Practical implications

- The findings of the present study suggest that the selection of distances to establish the distance–time relationship and calculate the CV is important for the prescription of swimming velocity during interval training.
- Selection of longer distances for the CV calculation (i.e. 200–400-m) may be more appropriate for the prescription of aerobic endurance training. Despite non-steady metabolic responses, repetitions of distances of 100, 200 and 400-m can be used during interval training with an exercise to rest ratio of 1:8. However, appropriate adjustment of the swimming pace should be applied according to the set distance and the distances used for the calculation of CV.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2011.03.002.

References