ORIGINAL ARTICLE

Rest periods effect on biophysical responses during interval training at critical swimming velocity

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ABSTRACT

This study aimed to examine the effects of rest periods on physiological and mechanical parameters during interval training (IT) using critical swimming velocity (CV). Ten male national-level competitive swimmers (19.5 ± 1.1 years old) swam 20 × 100 m (100IT) and 10 × 200 m (200IT) depend on critical velocity under different rest conditions. Rest periods for each IT were 10 seconds (R1) and 20 seconds (R2) per 100 m repetitive swimming distance. Heart rate (HR), rating of perceived exertion (RPE), blood lactate concentration, stroke rate, and stroke length (SL) were measured during all IT sets. HR significantly differed between R1 (164.0–173.0 beats per minute [bpm]) and R2 (151.7–165.1 bpm) throughout the 100IT but did not during the 200IT (160.1–173.5 and 157.3–167.8 bpm, respectively) ($p < .05$). Moreover, the mean SL during the 100IT was significantly lower in R1 than in R2 ($p < .05$). However, the HR and RPE increased significantly in both 100IT and 200IT irrespective of rest periods ($p < .05$). Therefore, all IT sets were appropriate conditions for endurance training. Rest periods may have influenced the physiological and mechanical stimulation in the 100IT at CV, suggesting that aerobic metabolism differs between conditions.
Keywords: Performance analysis, Athletes, Endurance training, Physiological cost, Heart rate, Stroke length, Training zone.

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INTRODUCTION

In competitive swimming, endurance training is categorized in terms of training intensity based on biophysical responses (Fenandes et al., 2024; Monteiro et al., 2023), and the total distance per category varies according to the swimmer's specialization (distance) (Hellard et al., 2022). Therefore, this information is useful for swimming coaches to identify the physiological and mechanical responses of endurance training sets.

Endurance training sets for competitive swimmers are mainly structured using interval training (IT), considering that the intensity of swimming sets can be easily adjusted according to the swimming velocity, repetitive swimming distance, and rest periods (Olbrecht et al., 1985; Billat, 2001). IT is also more effective than continuous training, which involves swimming at a constant pace, because it can maintain the same velocity for longer periods of time and reduce the decline in mechanical parameters (Almeida et al., 2022; Oliveira et al., 2012).

Shimoyama et al. (2003) found that the shorter the rest period, the higher the $\dot{V}O_2$ in IT in competitive swimmers. In other words, rest periods in IT may influence energy supply dynamics. Therefore, considering not only the swimming velocity and distance but also the rest periods is important to control the intensity of the swimming set in IT.

In IT, several physiological indices are employed to set swimming velocity, such as the onset of blood lactate accumulation (OBLA), maximal lactate steady state (MLSS), and anaerobic threshold (AT). However, these indices are often underutilized in swimming training due to complex procedures required, such as blood sampling and measurement of exhaled gases. The slope of swimming distance vs. time the regression line denotes the critical swimming velocity (CV) and is theoretically the maximum swimming velocity at which a swimmer can continue swimming for a long period of time without reaching exhaustion (Wakayoshi et al., 1992). CV correlates with physiological indices such as the OBLA (Wakayoshi et al., 1992; Wakayoshi et al., 1993), MLSS (Machado et al., 2011; Machado et al., 2019; Nikitakis et al., 2019), and AT (Wakayoshi et al., 1992), thereby used as a training intensity index that can be determined noninvasively.

Indeed, a study of continuous training with CV reported that the mean swimming time was 24.3 ± 7.7 min, with metabolic responses reaching maximal oxygen uptake ($\dot{V}O_{2max}$) and blood lactate concentration (BLa) being enhanced (Dekerle et al., 2010). Conversely, when IT was performed with CV, the heart rate (HR) and rating of perceived exertion (RPE) were enhanced, but the BLa remained stable. Furthermore, the intensity of the swimming set decreased as the repetitive swimming distances decreased in IT at CV (Funai et al., 2025). Thus, the influence of training style and repetitive swimming distance on physiological cost is evident in IT at CV.

However, the influence of rest periods on the physiological and mechanical parameters in IT at CV is still unverified. Clarifying the effect of rest periods on IT at CV would be a useful insight for coaches to design more effective endurance training strategies.

This study aimed to determine the effect of rest periods on physiological responses and mechanical parameters in IT using CV in national-level competitive swimmers. In this study, repetitive swimming distances of 100 and 200 m were applied for the IT, with two different rest periods in each of these IT protocols. We hypothesized that shorter rest periods have a higher physiological cost in both IT protocols. On the basis of the study results, we present practical applications of IT at CV for coaching situations.

MATERIAL AND METHODS

Participants

Ten nationally competitive male collegiate swimmers participated in the study (mean values for age: 19.5 ± 1.1 years, height: 168.0 ± 3.1 cm, body mass: 64.4 ± 4.2 kg, World Aquatics points: 738.1 ± 28.2). They specialized in middle-distance swimming (3 in 400 m freestyle, 2 in 400 m individual medley, 1 in 200 m butterfly, 3 in 200 m backstroke, and 1 in 200 m breaststroke) and had been competing for at least 8 years. All of them trained nine training sessions, which total over 45 km per week in water, as well as dryland workouts. They all provided written informed consent before participating in the experiment. None of the athletes reported any physical limitations, health problems, or injuries that would interfere with the study.

Study design

We instructed the participants to refrain from intense training for 24 h before the study, avoid any other exercise, and maintain a normal diet and sleep pattern throughout the study period.

In this experiment, we conducted four interval sessions after determining the CV in a 50 m indoor swimming pool (water temperature, 29.1°C ± 0.4°C). Participants performed front crawl swimming initiated with a push off start in all tests. Each test was preceded by a standardized warmup and a 20 min rest period. The standardized warmup (Neiva et al., 2017) included 200 m whole-body swimming (low–medium intensity), 2 × 100 m leg kick swimming (medium intensity), 4 × 50 m whole-body swimming (25 m drill/25 m low intensity), 6 × 50 m whole-body swimming (25 m race pace/25 m low intensity), and 100 m whole-body swimming (low intensity).

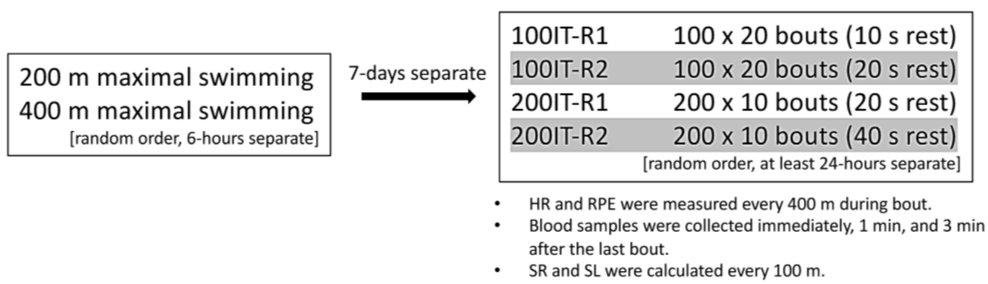


Figure 1. Experimental protocol of the study. HR: heart rate; RPE: rating of perceived exertion; SR: stroke rate; SL: stroke length.

CV determination

Swimmers performed 200 and 400 m maximal swimming bouts in a random order for CV determination, with an interval of 6 h between these two bouts (Figure 1). A linear regression between swimming distance and time was then obtained using the same method as that of Wakayoshi et al. (1993), and the slope of this line was used as the CV.

IT at CV

One week after the 200 and 400 m maximal swimming sessions, the swimmers performed 20 × 100 m (100IT) and 10 × 200 m (200IT) each under two different rest conditions. The rest periods in each IT were 10 and 20 s per 100 m of repetitive swimming distance. In other words, four tests were conducted: 10 s (100IT-R1) and 20 s (100IT-R2) for 100IT and 20 s (200IT-R1) and 40 s (200IT-R2) for 200IT in a random order based on the CV (Figure 1). These tests were performed randomly with at least 24 h apart and administered at the same time of the day (±1 hour) for each swimmer to minimize the influence of circadian fluctuations on performance. During the IT, the swimmers wore an underwater exercise-compatible Walkman (NW-WS623, Sony) to control their swimming velocity. This water-resistant neckband-type device was properly secured to the back of the head. Swimmers were instructed to pass through markers placed every 5 m at the bottom of the pool, in time with audio cues created according to their CV.

Measurements

For both the CV determination and IT, swimming times were measured by experienced coaching staff using a stopwatch (SVAS003, SEIKO, Japan). For physiological parameters during the IT, we measured HR and RPE every 400 m during the bouts. HR was measured using a wristwatch HR sensor (M600; Polar, Oulu, Finland), and RPE was determined by verbal questioning using the Japanese version of Borg's 6–20 scale (Onodera and Miyashita, 1976). BLa was measured using a portable lactate analyser (Lactate Pro 2, ARKRAY, Japan). Blood samples were extracted from fingertips immediately, 1 min, and 3 min after the last session, with the highest value recorded.

All IT sessions were filmed from land using a digital video camera (HDR-CX470 operating at 60 Hz; Sony, Japan) to calculate the stroke rate (SR) and stroke length (SL). This camera was positioned 10 m away from the swimmers at the centre of the pool, filming the swimmers vertically; then, SR and SL were analysed using video analysis software (OTL-8PZ, Octal, Japan). In all IT sessions, SR and SL were calculated every 100 m. In each 100 m, the mean stroke time was calculated from as many strokes as possible between 15 and 35 m in the first and second 50 m. The swimming velocity per 100 m was also calculated, and SR and SL were calculated using the following formula:

$$SR = 60 / \text{mean stroke time};$$

$$SL = \text{swimming velocity} \times 60 / SR.$$

The SR and SL for each 100 m were averaged, and these values were used for the statistical analysis.

Statistical analyses

A priori sample N was determined with G*Power ($f = 0.50$; $\alpha = 0.05$; $1-\beta = 0.80$). We present all performance, physiological, and mechanical parameters as mean ± standard deviation (mean ± SD). Data distribution normality was assessed using the Shapiro–Wilk test. We employed Student's *t*-tests to establish differences in BLa, mean SR, and mean SL between tests at 100IT and 200IT separately. HR and RPE during 100IT and 200IT were analysed by two-way analysis of variance of test and measurement points, and where significant main effects were found, significance was examined using the Bonferroni method for multiple comparisons. Furthermore, the effect size for *t*-tests and multiple comparisons was calculated using Cohen's *d*, with *d* classified as small (0.2–0.49), medium (0.5–0.79), or large (>0.8) depending on the absolute value (Cohen, 1988). A significance level of $\alpha = .05$ was used. All statistical data were analysed using BellCurve (version 4.07, Social Survey Research Information Co., Ltd., Tokyo, Japan) for Excel software (Microsoft Corp., WA, USA).

RESULTS

The mean swimming times in the 200 and 400 m maximal swimming sessions were 122.83 ± 3.73 and 261.80 ± 10.25 s, respectively, and the mean calculated CV value was 1.44 ± 0.07 m/s. Table 1 shows the BLa, mean SR, and mean SL in 100IT and 200IT. BLa did not significantly differ between the conditions for 100IT

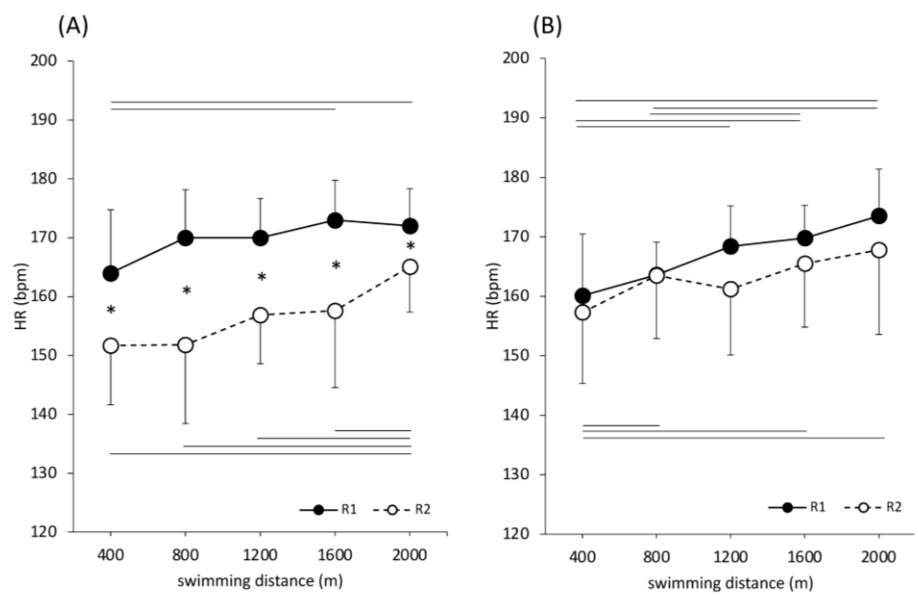
($p > .05$, $d = 0.03$) and 200IT ($p > .05$, $d = 0.05$). However, the mean SR ($p < .05$, $d = 0.37$) and SL ($p < .05$, $d = 0.31$) significantly differed between the conditions in the 100IT alone.

Table 1. Mean ± standard deviation of blood lactate concentration (BLa), mean stroke rate (SR) and mean stroke length (SL) during the 100IT and 200IT.

		R1	R2
BLa (mmol/L)	100IT	4.12 ± 2.53	4.04 ± 2.55
	200IT	4.86 ± 2.79	5.01 ± 2.81
Mean SR (cycles/min)	100IT	41.40 ± 4.75 *	39.91 ± 3.20
	200IT	41.26 ± 3.70	41.09 ± 4.03
Mean SL (m/cycle)	100IT	2.45 ± 0.28 *	2.52 ± 0.20
	200IT	2.44 ± 0.22	2.46 ± 0.24

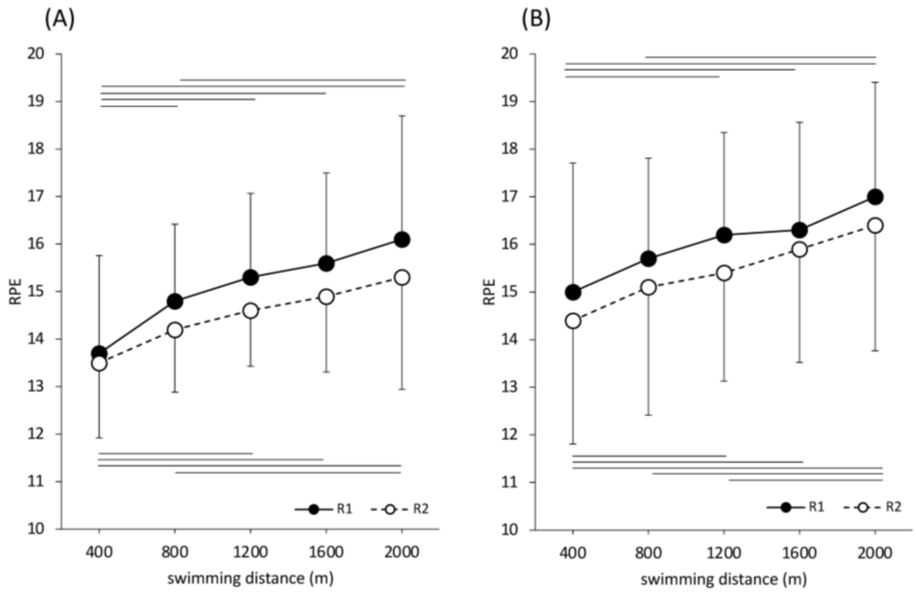
*Note. * Significant differences between R1 and R2 (p < .05). IT: interval training; R1: 10 s rest period per 100 m of repetitive swimming distance; R2: 20 s rest period per 100 m of repetitive swimming distance.*

Figures 2 and 3 show the changes in HR and RPE during 100IT and 200IT. For HR, 100IT-R1 (164.0 ± 10.6–173.0 ± 6.7 beats per minute [bpm]) was significantly higher than 100IT-R2 (151.7 ± 10. 1–165.1 ± 7.7 bpm) ($p < .01$, $d > 0.98$) at all measurement points. Conversely, HR did not significantly differ between 200IT-R1 (160.1 ± 10.4–173.5 ± 7.9 bpm) and 200IT-R2 (157.3 ± 11.9–167.8 ± 14.2 bpm) ($p > .05$, $d < 0.51$). As for RPE, no significant difference was noted between tests for both 100IT (R1: 13.7 ± 2.1–16.1 ± 2.6, R2: 13.5 ± 1.6–15.3 ± 2.4) and 200IT (R1: 15.0 ± 2.7–17.0 ± 2.4, R2: 14.4 ± 2.6–16.4 ± 2.6) in all measurement points (100IT: $p > .05$, $d < 0.47$; 200IT: $p > .05$, $d < 0.36$). In all tests, HR (100IT-R1: $p < .01$, $d > 0.91$; 100IT-R2: $p < .01$, $d > 0.70$; 200IT-R1: $p < .05$, $d > 0.95$; 200IT-R2: $p < .05$, $d > 0.52$) and RPE (100IT-R1: $p < .05$, $d > 0.59$; 100IT-R2: $p < .05$, $d > 0.58$; 200IT-R1: $p < .01$, $d > 0.49$; 200IT-R2: $p < .01$, $d > 0.41$) significantly increased.



*Note. Data are expressed as mean ± standard deviation. The lines above and below the points indicate significant differences (p < .05); * Significant differences between R1 and R2 (p < .05). R1: 10 s rest period per 100 m of repetitive swimming distance; R2: 20 s rest period per 100 m of repetitive swimming distance.*

Figure 2. Changes in heart rate (HR) during the 20 × 100 and 10 × 200 m interval training (A and B, respectively).



Note. Data are expressed as mean ± standard deviation. The lines above and below the points indicate significant differences (p < .05). R1: 10 s rest period per 100 m of repetitive swimming distance; R2: 20 s rest period per 100 m of repetitive swimming distance.

Figure 3. Changes in the rating of perceived exertion (RPE) during the 20 × 100 and 10 × 200 m interval training (A and B, respectively).

DISCUSSION

Previous studies of IT in competitive swimming used rest periods of 10–20 s every 100 m repetitive swimming distance (Almeida et al., 2021; Shimoyama et al., 1999). However, metabolic functions reportedly differ according to small differences in rest periods (Rodriguez and Mader, 2010). Therefore, the present study examined physiological and mechanical parameters in 100IT and 200IT under two conditions of 10 s and 20 s per 100 m repetitive swimming distance. Results showed that HR and mean SR were significantly higher in 10 s rest than in 20 s rest and that mean SL was significantly shorter in 100IT than in 200IT. In addition, HR and RPE increased significantly in both 100IT and 200IT irrespective of rest periods.

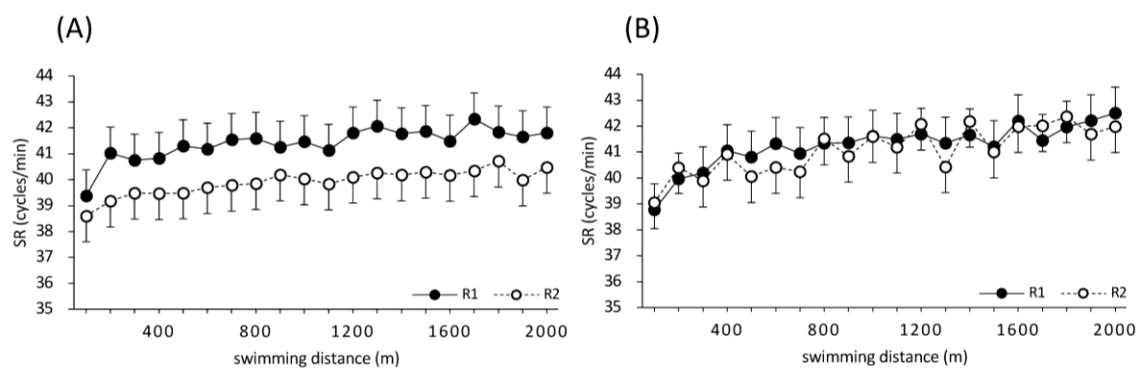
In a study measuring the metabolic response to IT and continuous training, $\dot{V}O_{2max}$ did not differ between the two training types (Almeida et al., 2022). However, the energy supply through the adenosine triphosphate–creatine phosphate (CP) system is higher during IT because creatine phosphate resynthesis is accelerated during the rest period and used as energy for the next bout (Fox et al., 1969). IT reportedly results in a lower energy supply from the glycolytic mechanism and a slower rate of lactate accumulation (Fox et al., 1969). Therefore, IT allows exercise to be sustained for longer periods at the same swimming velocity as continuous training (Demarie et al., 2000; Almeida et al., 2021).

Shimoyama et al. (2003) compared physiological responses in a test of 20 and 30 s rest periods during repeated 1 min intermittent swimming trials at OBLA swimming speed. Results showed that although BLa did not significantly differ between the two rest conditions, $\dot{V}O_2$ was significantly higher in the 20 s rest condition, while excess postexercise oxygen consumption (EPOC) was significantly higher in the 30 s rest condition. In IT, $\dot{V}O_2$ increases with a shorter rest period, possibly attributed to an increased contribution to the aerobic energy supply mechanism to compensate for inadequate CP recovery (Shimoyama et al., 2003). The increase in EPOC with prolonged rest reportedly reflects an increase in CP resynthesis (Piiper and Spiller, 1970).

Although BLa demonstrated no difference between the two rest conditions at 100IT in our study (Table 1), HR was consistently significantly higher in R1 (Figure 2). These results may support the report of Shimoyama et al. (2003). During IT, large amounts of oxygen accumulate in muscle myoglobin, even during short rest periods; consequently, oxygen depletion is minimized, thereby preserving the glycolytic pathways during exercise (Medbo et al., 1988). This phenomenon may explain the lack of difference in BLa in the present study. Additionally, $\dot{V}O_2$ may have been higher in R1 in the 100IT, and HR, a measure of the respiratory-cardiovascular system, would have shown a significant difference between the two conditions throughout the IT. A previous study reported a relationship between HR and the contribution of aerobic mechanisms in endurance training (Ribeiro et al., 2017). Hence, R1 may result in a higher oxidative metabolism training than R2 in 100IT.

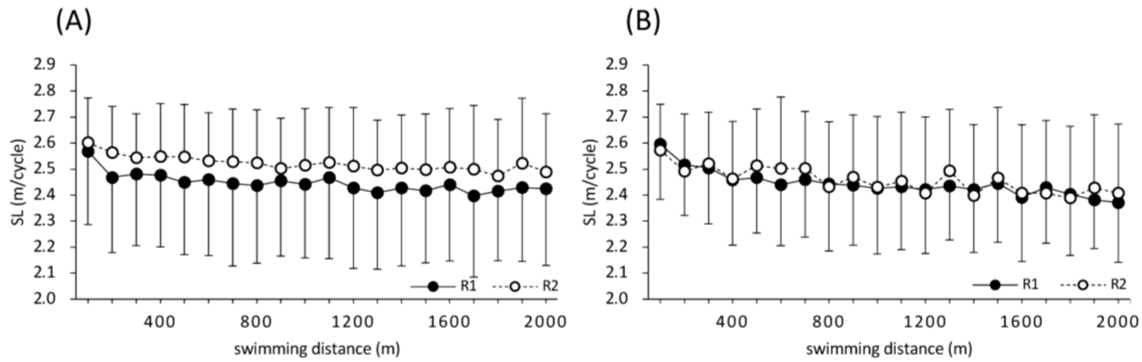
During the 200IT, HR did not significantly differ between R1 and R2. Simulations of CP recovery rates during IT by Rodriguez and Mader (2010) suggest that the majority of CP recovery occurs immediately after each bout until approximately 20 s, after which recovery proceeds slowly. The ability to recover CP in the early rest period may be a factor influencing intermittent exercise performance (Balsom et al., 1992; Blonc et al., 1998). However, this hypothesis could not be confirmed because we did not examine the CP recovery rates. Nonetheless, HR demonstrated no significant difference between the two conditions during the 200IT because the swimmers had a higher rate of CP recovery in the early part of each rest period.

Few studies have investigated the effect of rest periods in IT on mechanical parameters. In the present study, the mean SR and SL differed significantly between the conditions in 100IT (Table 1). SR (Figure 4) and SL (Figure 5) per 100 m also consistently differed between the conditions in 100IT. In progressive velocity tests of swimming, mechanical parameters rapidly change at metabolic threshold levels (Oliveira et al., 2012; Figueiredo et al., 2013). When swimming at a constant swimming velocity, an increase in SR and a decrease in SL occur as the respiratory and cardiovascular parameters increase (Pelarigo et al., 2016). Thus, physiological and mechanical parameters are closely related, and the differences in SR and SL in the present study may have been collateral evidence of differences in HR between conditions at 100IT.



Note. Data are expressed as mean ± standard deviation. R1: 10 s rest period per 100 m of repetitive swimming distance; R2: 20 s rest period per 100 m of repetitive swimming distance.

Figure 4. Changes in the stroke rate (SR) during the 20 × 100 and 10 × 200 m interval training (A and B, respectively).



Note. Data are expressed as mean ± standard deviation. R1: 10 s rest period per 100 m of repetitive swimming distance; R2: 20 s rest period per 100 m of repetitive swimming distance.

Figure 5. Changes in stroke length (SL) during the 20 × 100 and 10 × 200 m interval training (A and B, respectively).

Previous studies have investigated the training zone of CV. In one study using CV, continuous swimming training lasted only 24.3 min (Dekerle et al., 2010), given that BLa, HR, and RPE continued to increase and the metabolic responses reached $\dot{V}O_{2max}$. Training that induces these physiological responses is included in the severe-intensity domain. Moreover, the physiological cost of using CV for IT is lower than that for continuous training (Dekerle et al., 2010). Previous studies using CV for 100, 200, and 400 m IT sessions reported continuous increases in HR and RPE yet a steady state in BLa (Dekerle et al., 2010; Nikitakis et al., 2019; Rizatto et al., 2018). In other words, IT in CV belongs to the heavy-intensity domain. However, training zones that consider rest periods in IT using CV have not yet been validated.

In the present study, $\dot{V}O_2$ was not measured, and BLa was only measured at the end of the test, making the training zone difficult to determine. Not only HR but also RPE significantly increased in all conditions, occurring in both heavy- and moderate-intensity domains (Fernandes et al., 2024). However, the HR at 100IT was significantly lower in R2 than in R1. According to Fernandes et al. (2024), HR-based guidelines suggest that 160–170 bpm belongs to the heavy-intensity domain and 150–160 bpm to the moderate-intensity domain. Calvalho et al. (2020) and Monteiro et al. (2023) reported differences in SR and SL between the heavy- and moderate-intensity domains, suggesting that mechanical parameters can help identify boundaries between domains. On the basis of these findings, 200IT-R1, 200IT-R2, and 100IT-R1 corresponded to the heavy-intensity domain and 100IT-R2 to the moderate-intensity domain.

The heavy-intensity domain is an intensity at or near the metabolic threshold, where mechanical parameters collapse (Calvalho et al., 2020). At this intensity, fast paces can be maintained for prolonged periods of time without causing excessive fatigue, effectively improving the associated physiological parameters (Sperlich et al., 2023). The moderate-intensity domain was below the metabolic threshold. Sessions of this intensity make up a large proportion of the endurance training in competitive swimmers (Sperlich et al., 2023), with the aim of increasing the ability to oxidize pyruvate, lactate, and lipids throughout the body and improving basic endurance (Fernandes et al. 2024). Therefore, the IT protocols in this study are effective as endurance performance–enhancing training.

According to the results of the physiological and mechanical parameters in this study, practical applications can be suggested. Specifically, 200IT-R1, 200IT-R2, and 100IT-R1 can be used as training protocols, with BLa at 4–5 mmol/L and HR at approximately 160–170 bpm. Given that the physiological cost is close to the metabolic threshold, it can be used as intermittent race pace training for long-distance swimmers, especially during the strengthening phase. Moreover, 100IT-R2 can be used for training, with BLa at approximately 4 mmol/L and HR at 150–160 bpm. This IT provides a moderate load on the respiratory and cardiovascular systems and facilitates the maintenance of the swimming technique; hence, it can be used for training, especially in the early season and for improving basic endurance.

A limitation of this study is that the rest periods used in the IT are considered to be relatively short for regional-level, junior, and masters swimmers, indicating that the results can only be applied to national-level swimmers. Second, although our method of CV determination is traditional and simple, the possibility of a higher estimate of CV cannot be ruled out. For example, CV determined in 200 and 400 m maximal swimming bouts is higher than that determined in 200, 400, and 800 m maximal swimming bouts (Petrigna et al., 2022). Therefore, the results of this study can only be applied to CV calculated in this way. Conducting more research on IT using CV in the future is necessary.

CONCLUSION

The physiological and mechanical stimuli of R1 were higher than those of R2 in 100IT. In 200IT, the effect of rest periods on these stimuli did not need to be considered. All IT sessions showed increases in HR and RPE throughout, suggesting that they are appropriate training conditions for endurance performance. In particular, the 100IT-R1, 200IT-R1, and 200IT-R2 could be effectively used for race pace training protocols close to metabolic threshold levels, while the 100IT-R2 could have a positive effect on the increasing oxidative capacity of each energy source and improving basic endurance performance.

AUTHOR CONTRIBUTIONS

Conceptualization and design: Yuki Funai and Masaru Matsunami. Data Collection: Shoichiro Taba, Yuta Kanegawa, and Yuki Funai. Formal Analysis: Shoichiro Taba, Yuta Kanegawa, and Yuki Funai. Writing (original draft): Yuki Funai. Writing (review and editing): Masaru Matsunami, Shoichiro Taba, and Yuta Kanegawa.

SUPPORTING AGENCIES

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

The study was conducted in accordance with the aims of the Declaration of Helsinki and was approved by the Ethics Committee on Research Involving Human Subjects of Kumamoto Gakuen University (approved December 3, 2021).

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