

Physiological responses to an incremental swim test with different breathing frequencies in competitive male youth swimmers

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Abstract

Problem Statement: Both the aerobic and the anaerobic metabolic systems contribute to the majority of competitive swimming events with a significant energy supply coming from glycolysis, which can lead to blood lactate accumulation. Importantly, stroke technique is a significant determinant of the energy cost of swimming. Head turning for inhalation can potentially affect hydrodynamic resistance, in turn influencing performance, while breathing restriction may contribute to fatigue. **Purpose:** Sufficient breathing is more important in longer distances with greater aerobic demand, thus, it is expected that restricting oxygen delivery would alter the metabolic contribution of these durations. Therefore, the aim of this investigation was to compare metabolic responses to an incremental swim test with different breathing patterns in young competitive swimmers in the 200-m front crawl. **Approach:** Competitive male youth swimmers were recruited (n=8, Age=15±2, Height=177.5±9.6, Body weight=65.3±11.8) from a local swim club. A 7 x 200m incremental swim test was conducted with two different breathing rates: 1, breathing every three strokes (BR3) 2, breathing every five strokes (BR5) in a counterbalanced fashion and blood lactate and heart rate (HR) responses were recorded. Data were compared using a 2-way Analysis of Variance (ANOVA) with repeated measures. **Results:** Although there was a main effect for time (p=0.000), lactate and HR responses did not show significant condition by time interaction for the BR3 and BR5 breathing conditions (p=0.098 and p=0.262, respectively). Rating of perceived exertion (RPE) scores were almost identical on the 10-point Borg-scale between the two conditions at the completion of the swim test without any statistically significant difference (p=0.402). **Conclusions:** Experienced swimmers may attempt to control their breathing in order to increase swimming velocity by reducing drag without compromising performance due to lactate accumulation and fatigue. The current findings demonstrate that restricted breathing is feasible for longer (e.g. 200m) swimming distances.

Key words: controlled breathing, front crawl, lactate, heart rate, stroke rate

Introduction

Besides technical and morphological parameters, physiological factors play a significant role in swimming performance. Blood lactate profiling is a customary procedure to monitor physiological responses and exercise performance in endurance athletes. In turn, this information can be used to monitor acute and chronic physiological responses and to implement successful, individualized training interventions for the tested athletes. Although, these analyses are commonly employed in running and cycling, there is considerably less information available in swimming, regarding blood lactate profiling.

Both the aerobic and the anaerobic metabolic systems contribute to the majority of competitive swimming events, especially from 50 to 400m distances with 30sec to 4min durations. Several studies have reported that 37–63% of the energy supplied for events of these durations comes from glycolysis, therefore these events can lead to significant blood lactate accumulation (Wells, Selvadurai, & Tein, 2009). Research on glycolytic function in youth athletes has received considerably less attention, but most studies agree that this age group have less developed anaerobic metabolism compared to adults. It has been suggested that starting at adolescence, there are minute differences in the athlete's ability to produce lactic acid, as posttrace blood lactate only increased by 0.09 mmol·L⁻¹ per year with chronological age (Vescovi, Falenchuk, & Wells, 2011).

Vescovi and colleagues (Vescovi et al., 2011) found that blood lactate concentrations were the highest after the 100m and 200m events during the finals at the Canadian Championship regardless of swim stroke, while other researchers observed the highest glycolytic contribution in the 100m and 200m front crawl events in youth and young swimmers (Kachaunov, 2018; Zacca et al., 2014). Furthermore, it has been demonstrated in competitive swimmers that anaerobic contribution correlates with swimming performance in distances up to 400 meters (Campos et al., 2017). Others have found that even minor changes in swimming speed markedly affected

blood lactate concentration near the LT (Hering & Stepan, 2021). Importantly, stroke technique is a significant determinant of the energy cost of swimming (Chatard, Collomp, Maglischo, & Maglischo, 1990).

In front crawl swimming, breathing rate is synchronized with the strokes in step with exhalation and inhalation (Štrumbelj, Kapus, Ušaj, & Kapus, 2007). While expiration can be executed any time without restrictions during the stroke cycle, the timing and velocity of inspiration can affect swimming performance (Aspenes & Karlsen, 2012). Swimming requires forced inspiration within the stroke cycle with an entrained breathing pattern that can determine breathing frequency, resulting in hypoxia and hypercapnia (Leahy et al., 2019). In addition, in front crawl, underwater swimming after a turn requires breath holding, which can also lead to a period of apnea (Grossman, Lim, Murias, & Belfry, 2021). Breathing may be completed on either side with a unilateral or bilateral pattern. Head turning for inhalation can potentially affect swimming efficiency and hydrodynamic resistance, in turn influencing velocity and performance. In fact, Pedersen et al. (Pedersen & Kjendlie, 2006) calculated that the time difference between one breath and no breath conditions amounted to 0.03sec over a ten meter distance, which can be a meaningful performance handicap. This finding was confirmed by others, indicating that swimming velocity was significantly faster in the no breathing condition in front crawl sprint (McCabe, Sanders, & Psycharakis, 2015). Thus, according to the previous authors all swimmers can benefit from the refinement of breathing technique and breath control to improve performance. Another report stated that higher anaerobic energy requirement was related to increased controlled breathing frequency at a specified swimming intensity (Cardelli, 2000). Interestingly, it has also been observed that expert swimmers take fewer breaths to maintain an optimal streamlined position and efficient propulsion (Cardelli, 2000). By minimizing body roll and consequent drag, swimmers can achieve higher velocities with the same energy expenditure (Sos, 2019). The most frequently used and often recommended technique is one breath every two strokes, which seems to be appropriate for distances longer than 100m (do Couto, Franken, & Castro, 2014; Pedersen & Kjendlie, 2006). However, breathing restriction may contribute to fatigue, while higher frequency breathing can affect swimming performance by decreasing velocity (do Couto et al., 2014).

The majority of studies that analyzed physiological responses to restricted breathing employed swimming protocols up to 100m distances at submaximal intensities. Therefore, it is not entirely clear how various breathing patterns influence anaerobic parameters, especially in youth swimmers at longer distances (e.g. >100m). Although evidence exists that in sprint events up to 100m lactate response is unaffected by breathing frequency, it remains unclear whether controlled breathing influences HR and lactate responses at longer distances. Sufficient breathing is more important in events with greater aerobic demand, thus, it is expected that restricting oxygen delivery would alter the metabolic contribution of these durations. Therefore, the aim of this investigation was to compare metabolic responses to an incremental swim test with different breathing patterns in young male competitive swimmers in the 200-m front crawl. An incremental swimming protocol with the same 200-m distance has been shown to reliably assess metabolic parameters (Monteiro et al., 2022). We hypothesized that as opposed to shorter distances, swimming with a breathing rhythm of every 5 vs 3 strokes would result in higher blood lactate and heart rate responses in competitive youth swimmers.

Materials & methods

Subjects

Competitive male youth swimmers ($n=8$, Age= 15 ± 2 , Height= 177.5 ± 9.6 , Body weight= 65.3 ± 11.8) were recruited from a local swim club to participate in the study. All swimmers learned to swim by the age of five and were currently ranked in the top ten at the national level in their respective age groups and possessed a minimum of six-year competitive experience. All participating swimmers regularly competed in front crawl style events. The participants and their guardians were informed about the procedures and gave written consent before the commencement of the study. The study was also approved by the University's ethics committee and was carried out in accordance with the Declaration of Helsinki on Human Subjects. The swimmers were also instructed not to alter their normal diets and physical activity during the study. During the course of the study the swimmers engaged in their usual workout routine, consisting of 17 to 20 hours of both swimming and dryland training per week. The swimming workouts focused on aerobic conditioning, while the dryland practices included trunk and upper body exercises, using resistance bands and dumbbells.

Procedures

Swim Test We used a multistage incremental swimming protocol as described previously by Pyne and coworkers (Pyne, Lee, & Swanwick, 2001). Briefly, the swimmers completed seven 200-meter front crawl swim series with target times set based on each swimmer's personal best performance (Table 1). Every swimmer completed the test on two occasions 14 days apart in a randomized order with two different breathing rates: 1, breathing every three strokes (BR3) 2, breathing every five strokes (BR5).

The 7 x 200m incremental swim test was conducted in a counterbalanced fashion with random assignment to either the BR3 or BR5 condition. All testing took place in a 25-m competition swimming pool between 8am and 12pm with each swimmer starting at the same time on both occasions. The swimmers utilized a push start and performed the test in pairs in two non-adjacent lanes. All swimmers performed a 200m warm-up swim at a self-selected pace, then following a ten-minute break the swimming test commenced. Five minutes

passive rest was provided between each stage. Swim time (rounded to the nearest second), and the number of strokes were recorded for each 200-m swim, while rating of perceived exertion (1-10 Borg scale) was taken after the final stage. Trained research assistants measured the swim times manually, including each lap time, using a stop watch and also recorded the stroke rates for each swimmer. Instructions were provided during every lap in order to maintain a constant pace for the entire distance.

Table 1. Swimming test protocol

Swim series	% of best time
1	70
2	75
3	80
4	85
5	90
6	95
7	100

Heart Rate Measurement and Blood Lactate Analyses

Resting blood lactate values were recorded during quiet sitting before warm-up. Upon the completion of each 200-m distance, the swimmers exited the pool and rested in a sitting position for five minutes, before the initiation of the next interval. During the rest period, blood samples were taken from the finger tip for lactate analyses at one minute post-swim, using a hand-held blood lactate analyzer (Lactate Scout, EKF Diagnostics, Cardiff, UK). A wifi-based telemetry system (Hosand aqua, Hosand Technologies Srl, Verbania (VB), Italy) was used to continuously monitor heart rate (HR) throughout the swim and rest intervals with the last measure taken one minute after the completion of the test. HRs were recorded for data analysis immediately at the finish of each swim series.

Statistical Analyses

Normality was rejected based on Shapiro-Wilks test, thus Man-Whitney test was performed, which did not show a significant difference. Then data were compared using 2-way Analysis of Variance (ANOVA) with repeated measures with Greenhouse-Geisser correction, while rating of perceived exertion (RPE) data was evaluated by a paired sample T-test. All analyses were performed using SPSS statistical software, version 28 (SPSS, Inc., Chicago, IL, USA). Statistical significance was set at $p \leq 0.05$. Data are presented as mean $\pm$ SD.

Results

Lactate concentration and Perceived exertion

Although, Lactate concentrations started to vary between the 3BR and 5BR conditions from swim series five until the last completed swim, and there was a main effect for time ($p=0.000$), condition by time interaction was not statistically significant ($p=0.098$) (Figure 1).

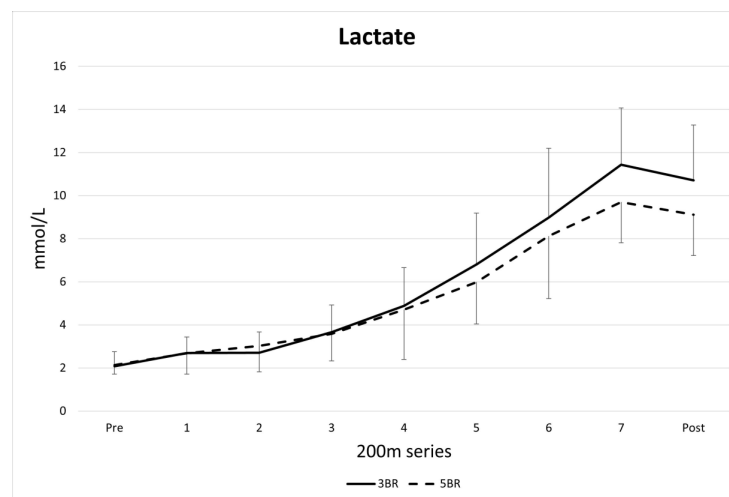


Figure 1. Lactate responses to 3BR and 5BR conditions at rest and 1 min after each swim series.

Moreover, according to the 10-point Borg-scale, RPE scores were almost identical between the two conditions at the completion of the swim test without any statistically significant difference ($p=0.402$) (Figure 2).

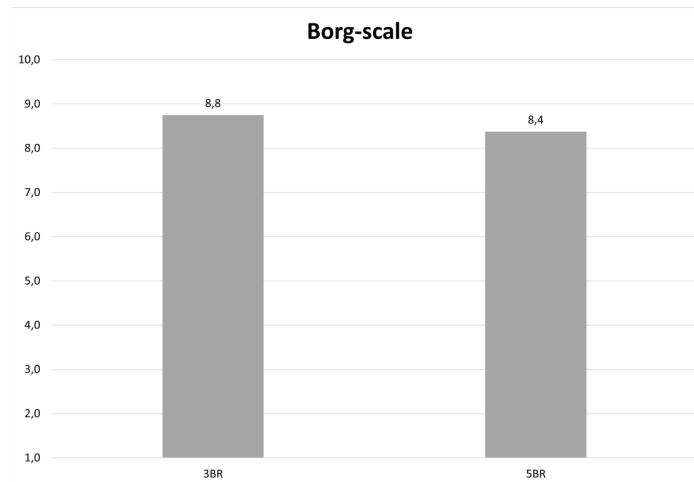


Figure 2. Rating of Perceived Exertion after the completion of the swim test.

Heart Rate

Although there was a main effect for time ($p=0.000$), HR responses did not show significant condition by time interaction for the BR3 and BR5 breathing conditions ($p=0.262$) (Figure 3).

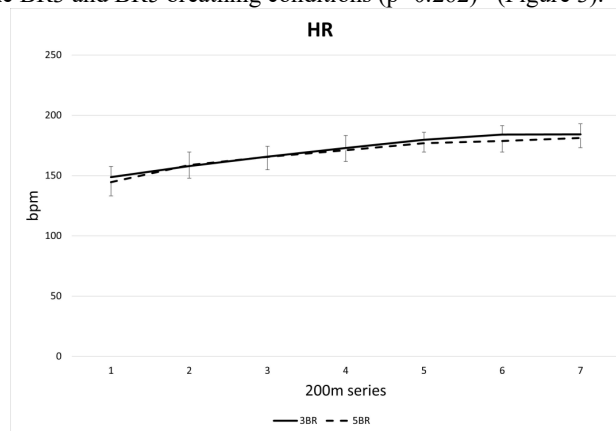


Figure 3. Heart Rate responses to 3BR and 5BR conditions after each swim series.

Performance responses

Stroke rate gradually increased from series one to series seven in concert with swimming velocity showing a main effect for time ($p=0.000$), however, condition by time interaction was not statistically significant ($p=0.701$) (Figure 4.)

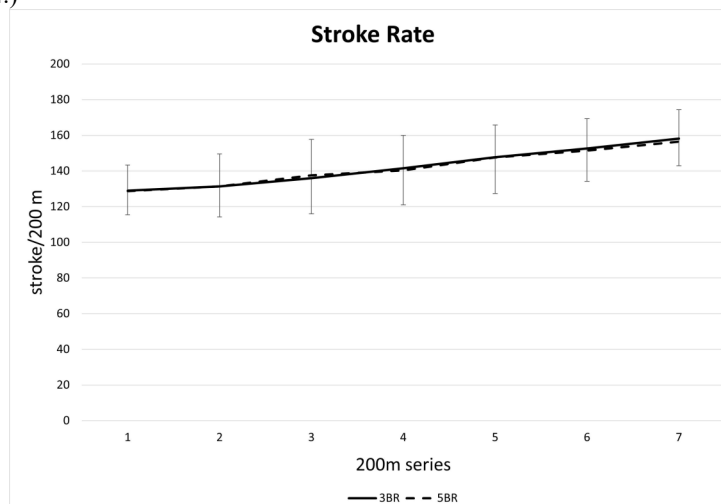


Figure 4. Stroke Rates for the 3BR and 5BR conditions in each swim series.

Discussion

The primary outcome of the current study is that lactate and HR responses did not differ between the 3-stroke and 5-stroke breathing patterns during a 7 x 200m incremental freestyle swim test in competitive youth swimmers. 3BR is considered a normal rate in our study, while 5BR is a restricted pattern as the swimmers had to hold their breath compared to their regular training and competition technique. In fact, breathing every two, three and four strokes appeared to be the most common rates in the first part of the 100m distance, with a few swimmers, among them the winners, maintaining three or four stroke breathing pattern for the entire race during a National Championship (Pedersen & Kjendlie, 2006). Also, swimming performance was better with a restricted breathing pattern of every four and six strokes compared to every two strokes in a study by Couto and coworkers (do Couto et al., 2014).

The majority of the available literature show no differences in lactate responses between normal/unrestricted and restricted breathing techniques in freestyle swimming (Key, MA; Eschbach, CL; Bunn, 2014; Papadimitriou, Tsalis, & Loupos, 2020; West, Drummond, VanNess, & Ciccolella, 2005), however, this information is limited to sprint tests only. Key et al. (Key, MA; Eschbach, CL; Bunn, 2014) compared 2-3 stroke/breath cycle with seven stroke cycle breathing, while West and colleagues (West et al., 2005) analyzed self-selected (~2-3 stroke/breath) vs eight stroke per breath patterns. Although, in our study the breathing frequencies in the two conditions were less varied compared to the above mentioned investigations, we observed the same outcome, therefore regardless of the degree of breathing restriction lactate levels did not increase above the normal breathing pattern. In youth swimmers the results were similar; either no statistically significant difference between normal and restricted breathing conditions or the normal breathing patterns resulting in higher lactate responses, depending on the swimming distance (Papadimitriou et al., 2020). Also, in an older investigation blood lactate concentrations were Immol/L higher on average with normal breathing during both the 100m and 200m distances (Holmer & Gullstrand, 1980). These findings seem paradoxical, since the reduced oxidative metabolism (Holmer & Gullstrand, 1980; Town & Vanness, 1990) should be countered by increased anaerobic energy production.

Various theories have been put forward to explain this phenomenon. For instance, it was proposed that the larger muscular work, thus energy demand involved with head turning for inhalation may contribute to increased lactate concentration compared to no or fewer breath cycles over the same distance (Papadimitriou et al., 2020). However, this extra work does not appear to be significant enough, especially in shorter distances, thus it remains to be demonstrated that it would lead to higher lactate accumulation with more frequent breathing. Moreover, apparent hypercapnia during restricted breathing may limit the metabolic response, because elevated carbon dioxide levels in the blood can inhibit lactate accumulation (Holmer & Gullstrand, 1980; Key, MA; Eschbach, CL; Bunn, 2014). In our study we did not analyze carbon dioxide in the blood, thus we can neither confirm nor refute this rationale. On the other hand, this phenomenon has been described during both swimming and cycling exercises (Jakovljevic & McConnell, 2009; Town & Vanness, 1990; West et al., 2005).

It is also possible that the sampling time influences the lactate values. In the current investigation, we collected blood samples only one minute post swim, therefore lactate may not have diffused completely from the working muscles to the blood at this time point. However, others also failed to show significant differences in blood lactate concentration at three and five minutes post swim, although the largest variation between the conditions occurred at the five-minute time point (Key, MA; Eschbach, CL; Bunn, 2014). In addition, in adolescent swimmers lactate responses to restricted breathing did not diverge even seven minutes after the completion of the swim (Tsalis, Poularinos, Loupos, & Mougios, 2009), which would negate the previous explanation.

In the current study HR responses were also nearly identical between the two breathing conditions after every swim series. Conflicting finding was reported previously; the controlled breathing trial resulting in approximately 10 beats per minute lower HR in a 100-yr freestyle swim (Key, MA; Eschbach, CL; Bunn, 2014). However, an investigation by Town and coworkers (Town & Vanness, 1990) demonstrated that HR did not differ even when two, four, six and eight strokes per breath cycles were tested. Moreover, highly trained swimmers exhibited the same tendency before, as no significant difference in HR was found between normal- and various controlled breathing strategies (Dicker, Lofthus, Thornton, & Brooks, 1980). The possible cause of this inconsistency may lie in the various protocols that these prior studies employed compared to our own. For instance, the older reports used tethered swimming protocols (Dicker et al., 1980; Town & Vanness, 1990), while the normal and controlled breathing conditions were much more diverse (2-3 vs 7 strokes) in the study by Key and colleagues (Key, MA; Eschbach, CL; Bunn, 2014) compared to the current inquiry. Moreover, among these reports ours was the only one that used an incremental swim test with longer distances (200m). Most comparable to the current method, a 2 x 200m front crawl swim with breathing every two vs four strokes at 90% of race pace resulted in similar HR responses (Jakovljevic & McConnell, 2009).

In our incremental protocol the athletes were required to increase swimming velocity, thus stroke rate increased concomitantly throughout the swim series. However, there was no difference between the normal and restricted breathing conditions, indicating that the swimmers were able to maintain their stroke efficiency. Key et al. (Key, MA; Eschbach, CL; Bunn, 2014) also observed that stroke counts were almost identical for the 100-

yard swim in the normal and controlled breathing conditions. On the other hand, it has been reported that controlled breathing interfered with proper stroke mechanics as stroke rate increased consistently with breathing restriction (Town & Vanness, 1990). However, this study employed a tethered swimming protocol at a constant workload, while in our current investigation the swimmers swam freely, identical to routine training and competition, which may explain this discrepancy.

Conclusions

We have shown that 3BR and 5BR breathing frequencies in an incremental swim test did not result in different metabolic and performance responses in competitive youth swimmers, therefore we rejected our original hypothesis. Accordingly, experienced swimmers may attempt to control their breathing in order to increase swimming velocity by reducing drag without compromising performance due to lactate accumulation and fatigue. Most coaches and researchers recommend restricted breathing patterns up to 100-m distance (do Couto et al., 2014; Pedersen & Kjendlie, 2006), however, as the current findings demonstrate this strategy may also be feasible for longer (e.g. 200m) distances. As opposed to the belief of most swimming coaches who prescribe hypoxic workouts with breath holding (Burtch et al., 2017), restricted breathing does not seem to provide additional training stress in front crawl, at least in the distances investigated to date. This notion was also confirmed by subjective RPE measure, indicating that the swimmers reached the same level of fatigue in both conditions at the end of the testing protocol.

Nevertheless, the optimal breathing pattern for various swimming distances is unclear and it likely depends on each swimmer's ability, technique and physiological characteristics. Also, the question remains: from which distance and in which swimming style would controlled breathing affect the measured physiological parameters? Moreover, to date no investigations analyzed metabolic and performance responses along with blood carbon dioxide measurements in a real-world setting to delineate the underlying mechanisms of the paradoxical lactate response to restricted breathing.

Conflicts of interest: No funding has been received for the preparation of this manuscript and all authors declare no conflicts of interest.

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