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Full Length Article

Do 5% changes around maximal lactate steady state lead to swimming biophysical modifications?

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ABSTRACT

Our purpose was to examine the swimming biophysical responses at velocities (v) of 97.5, 100 and 102.5% of the maximal lactate steady state (MLSS). Ten elite female swimmers performed three-to-five 30-min constant tests at imposed paces to determine 97.5, 100 and 102.5%MLSS v. Gas exchange, blood lactate concentration ([La-]), stroke rate (SR) and v were determined during each test. The v values at 97.5, 100 and 102.5%MLSS were 1.21 ± 0.07, 1.24 ± 0.07 and 1.27 ± 0.07 m.s^{-1}, respectively. Oxygen uptake ($\dot{V}O_2$) and Pulmonary ventilation ($\dot{V}E$) increased as function of v. SR and stroke length (v/SR = SL) increased as a function of v. All measured variables were constant as a function of time at 97.5%MLSS and 100%MLSS. At 102.5%MLSS SR increased (3.5%) and stroke length (SL) decreased (3.5%) as a function of time. While $\dot{V}O_2$ was constant at 102.5%MLSS, [La-] and $\dot{V}E$ increased as a function of time, suggesting hyperventilation, at v's of 97.5%MLSS and 100%MLSS swimmers completed the 30 min swim in spite of decreased SL and increased SR. However, the decrease in SL and increased SF were accompanied by increased [La-] and $\dot{V}E$ and resulted in the inability of most swimmers to complete the 30 min swim presumably due to fatigue at 102.5%MLSS.

1. Introduction

At low exercise intensities metabolism is from primarily aerobic sources. However, when exercise intensity increases to near or above maximal aerobic power a mixture of aerobic and anaerobic sources are used, leading to time dependent increase in muscle and blood lactate. Since the 1960s, researchers have struggled to understand and define the physiologic state where there is a significant increase in blood lactate concentration ([La-]) (anaerobic threshold – AnT). Of these attempts, a recent initial definition was termed endurance performance limit (Hollmann, 2001), which has been redefined as aerobic-anaerobic threshold, individual anaerobic threshold, anaerobic threshold, lactate turnpoint, and individual lactate minimum, among other terms (Faude, Kindermann, & Meyer, 2009). Another concept related the AnT to the maximal

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intensity that can be maintained as function of time without blood lactate accumulation, i.e. the maximal lactate steady state – MLSS (Beneke, 2003). This exercise intensity has been used for the evaluation of aerobic capacity for endurance performance and training prescription (Beneke & von Duvillard, 1996; Faude et al., 2009).

The MLSS is considered by many as the direct method for the evaluation of aerobic capacity (Beneke, 2003; Beneke & von Duvillard, 1996; Faude et al., 2009). MLSS is identified as the highest steady state [La-] that can be maintained during prolonged sub-maximal and constant workload exercise (Beneke, 2003; Beneke & von Duvillard, 1996). At intensities below and at the MLSS there is a steady-state of [La-] as function of time and exercise can be sustained (Baron, Dekerle, Depretz, Lefevre, & Pelayo, 2005). However, when the exercise is performed at intensities above the MLSS intensity, a significant increase in [La-] is observed as function of time, which is associated with voluntary exhaustion (Beneke & von Duvillard, 1996; Heck et al., 1985).

Although the concepts of AnT and MLSS have been previously used to characterize swimming performance, it is commonly accepted that there are bioenergetical and biomechanical factors that may influence these parameters. Further examination of these factors is needed to better understand their possible interaction, helping to understand the swimmers' adjustments that occur at intensities around MLSS (Faude et al., 2009) and as a function of swimming time.

The inability to maintain a predetermined swimming intensity (fatigue) may be due to the inability to sustain optimal biomechanical parameters, as the aerobic system bioenergetics has been shown to be stable as a function of time (Baron et al., 2005). Physiological mechanisms other than metabolism may be time-dependent, such as the ability to sustain force and its application to the water (Baron et al., 2005; Dekerle, Nesi et al., 2005; Pelarigo, Denadai, & Greco, 2011). Thus, biomechanical factors could change the MLSS swimming velocity (v) (Pelarigo et al., 2011), leading to a reduced v or swim time.

We are unaware of any studies that have evaluated bioenergetical and biomechanical factors at intensities at or around the 100%MLSS in swimming. To examine the interrelationships of biophysical factors they must be evaluated not only as a function of intensity, but also as a function of exercise duration to understand what limits performance at these v's. Thus, the purpose of this study was to analyze the responses of bioenergetical and biomechanical factors while swimming at 97.5, 100 and 102.5%MLSS. We hypothesized that swimming intensities up to 100%MLSS would not require progressive adjustments of bioenergetical and biomechanical factors and not limit exercise endurance up to 30 min. However, we hypothesized that swimming above 100%MLSS would compromise bioenergetical and biomechanical factors which would affect the swimmers ability to sustain set exercise intensities (v) for 30 min.

2. Methods

Ten elite female swimmers (mean ± SD; aged 17.6 ± 1.9 years, height 1.70 ± 0.05 m, body mass 61.3 ± 5.8 kg and percentage of body fat mass 15.5 ± 2.9%; maximal oxygen uptake – $\dot{V}O_{2max}$ 54.9 ± 6.7 mL.kg.min^{-1}), who specialized in middle- and long-distance swimming events participated in the present study. The measurements of body mass and fat were assessed by a segmental body composition analyzer (Tanita, TBF 305, Tokyo, Japan).

Subjects had, at the least, seven years of experience as competitive swimmers and their mean performance over the 400 m freestyle swim was 88.0 ± 3.4% of the 2016 short course world record. The study was approved by the local ethics committee and was performed according to the Declaration of Helsinki. Subjects and/or parents gave their written informed consent before participation in experiments.

The test sessions were performed in a 25 m indoor swimming pool, with water temperature of 27–28 °C and air humidity of 40–60%. Swimmers were advised to refrain from intense training for at least 24 h before the experiments. The tests were all conducted within a seven day period, at the same time of the day (±2 h) to minimize the effect of circadian rhythm. In all test sessions, the swimmers performed a 1000 m warm-up at low/moderate aerobic intensity. During the tests, swimmers swam front crawl and used in-water starts and open turns without underwater glides.

First, the swimmers performed an intermittent progressive protocol until voluntary exhaustion to determine the individual anaerobic threshold (IAnT). The predetermined initial v of the swim was set at ~80% of the subject's best time for the 400 m front crawl race (S400), the v was increased by 0.05 m.s^{-1} for each subsequent step until voluntary exhaustion. Thirty seconds rest intervals were observed in-between each swim. The distance of each step of the incremental test was 200 m.

Earlobe capillary blood samples (5 μL) were collected and analyzed for [La-] with a portable lactate analyzer (Lactate Pro, Arkray, Inc., Kyoto, Japan). [La-] was measured at rest and in the first 30 s after each step of the incremental test and, immediately after exhaustion and at each 2 min of recovery from the last step until the [La-] peak was found. The IAnT was assessed by the relationship between [La-] and v with the lactate inflexion point determined as the interception between a linear and exponential regressions to estimate the v where [La-] increased exponentially (Fernandes et al., 2006; Machado, Almeida, Morais, Fernandes, & Vilas-Boas, 2006). If a swimmer did not achieve their maximal v and/or exhaustion with the pre-defined increases in v, the fastest v the subject completed was used to determine the minimum v eliciting the $\dot{V}O_{2max}$.

After determining IAnT, each swimmer performed three-to-five 30 min submaximal constant swimming tests at imposed paces to assess the v where a MLSS was achieved and maintained (100%MLSS). The swimming v was set and maintained using a visual underwater pacer (GBK-Pacer, GBK Electronics, Aveiro, Portugal), with a light strip on the bottom of the pool. The light strip had lights located 2.5 m apart for 25 m. The swimmers followed the flashing lights to maintain the predetermined v's. The swimmers were instructed to swim at a speed by looking at and following the visual signal as the lights