Introduction

Blood lactate concentration (Bla) and heart rate (HR) have been used to evaluate and predict performances during submaximal and maximal swimming. The Bla concentrations are commonly used to establish the optimal training intensity by determining the interrelationships among Bla, swimming velocity (v), and HR in prolonged and interval-type training [11,14,23,28]. These relationships allow coaches to objectively control the intensity of swimming during training so that they can focus on energy systems necessary to optimize performance in a chosen swimming event.

Abstract

Exercise testing in water has been used to follow the progression of conditioning during regular training in swimmers. The present study examined the effects of pool length in eleven male swimmers on a set of 5 × 200-m freestyle swims with increasing speed from submaximal to maximal. Mean velocity of swimming, blood lactate and heart rate were examined in both 25-m and 50-m pools. Turning benefit as a marker for turning skill was measured separately by a underwater video system (speed difference between pre- and post-turning) during short all-out swims. Maximum force during swimming was measured in tethered swimming and explosive strength of leg extensor muscles was evaluated by a counter movement jump. The significantly higher (p = 0.033 – 0.000) blood lactate values for the 50-m pool as compared to the 25-m pool were found at each point of swimming velocity versus blood lactate curve. The highest post-test lactate level was 7.36 ± 1.47 mmol·l⁻¹ in the short course and 8.24 ± 1.55 mmol·l⁻¹ (p = 0.033) in the long course. The maximum swimming velocity was significantly greater (4.5%) in the 25-m pool swimming (1.38 ± 0.11 m·s⁻¹ vs. 1.32 ± 0.12 m·s⁻¹; p = 0.000). The heart rate values were significantly (p = 0.020 – 0.000) lower in the short course than in the long course at all points of submaximal velocity with a mean difference of 7.3 ± 0.7 bpm. Heart rate was equal (172 ± 14 vs. 172 ± 14 bpm) after the maximum swims in both short and long course. The turning benefit in the short maximum swim was 0.12 ± 0.05 m·s⁻¹ (8.1 ± 3.2%), correlating positively with the difference in maximal swimming velocity between the short and long-pool swims (r = 0.59; p = 0.029), with the maximum force during tethered swimming (r = 0.75; p = 0.004) and with the vertical jumping height in the counter movement jump (r = 0.55; p = 0.039).

We conclude that the pool length has a strong effect on blood lactate concentration and heart rate with greater swimming velocity in the short course pool.

Key words

Swimming · exercise testing · blood lactate · turning skill · performance
Short (25 m) and long course (50 m) swimming have been applied for both competition and training. The difference in competitive swimming performance between 25- and 50-m pools is well appreciated in swimming science. Statistics of the competition results are held separately due to significantly faster speeds in the short course. The short course has been considered faster mainly because of extra turns [17,20,30,36]. The extra turns offer swimmers several advantages, including increased velocity after each turn and a period of relative inactivity during which moderate exercise recovery results [20]. Both of these factors may allow for advantageous transitory reduction of lactate concentration in blood and muscle and also lower HR specifically at submaximal intensity.

Wirtz et al. [36] made comparisons between highly skilled males and females competing in both 25-m and 50-m pools. They reported that male swimmers could gain more advantage from the short course swims as compared to females. The major reason for the observed differences was the better ability of the male swimmers to reach high velocities (\(v\)), especially during turning. Telford et al. [30] studied maximal post-competition Bla in highly ranked Australian swimmers during 25- and 50-m pool competitions in successive weeks, however, not controlling the order of performances in the different pools and not controlling the training regimens preceding the competitive time trials. The average maximal Bla for males and females was 3.8 ± 0.6 mmol·l–1 greater in the 50-m than the 25-m pool. Their conclusion was simply that racing in the 50-m pool appeared to elicit higher Bla than in the 25-m pool, and males and females demonstrated similar trends. Lowenstein et al. [20] produced a similar design in training conditions making comparisons between 50-m and 25-m pools, and controlling the order of 200-m freestyle swims in the two types of pools, as well as the pre-exercise Bla. The results suggested that when swimming at comparable intensities and distances in pools of different length, a long course pool will produce 13.8% higher peak Bla than a short course pool. Maximum \(v\) was found to be approximately 3.0% higher in the short course, while the post-swimming heart rates (HR) did not differ between the pools. Thus, these studies [20,30,36] dealing with maximal competition or competition like performances suggest that the differences in the performance times between short and long course swims have two explanations: mechanic and metabolic. Mechanical factors are dealing with matters over technique and muscular power, and metabolic factors over energetics and endurance capacity of the swimmers. However, there is a lack of scientific approaches concerning the combined metabolic and mechanical effects of pool length in training conditions where both sub-maximum and maximum intensity levels are included. We hypothesize that the pool length may influence Bla concentration and HR also at submaximal swimming intensity. As measurement of Bla concentration and HR during swimming may ultimately influence choices of exercise training strategies, adaptive responses to training, and competition performance, the aim of the present study was, firstly, to evaluate the mean \(v\) of swimming, post-swim Bla, and post-swim HR during an incremental set of 200-m swims between 25- and 50-m pools. Secondly, this study aimed to examine the influences of turning skill and muscular power on the results obtained by the two training conditions.

### Methods

#### Subjects and experimental design

Eleven male athletes (3 swimmers, 6 triathletes, 2 finswimmers) volunteered as subjects. Their physical and performance characteristics are presented in Table 1. The subjects performed two swimming test sessions in a randomized order with two days of recovery. Swimmers were advised to avoid heavy training during the two days in-between. The test sessions consisted of five 200-m front crawl swims in both 25-m and 50-m pool. The subjects performed a 200-m maximal time trial (see Table 1 for Time 200) in a 50-m pool three days prior to the first test session. The starting \(v\) was set according to the 200-m test swim by adding 50 s to the test time. Thereafter, the \(v\) was increased by 10 s in each of the successive 200-m swims. The last swim was performed with maximum effort independent from the previous ones. The resting interval between the 200-m repetitions was 1 min. The two test sessions were executed with equal procedure and with the help of pace-maker lights under-water adjusting the \(v\) according to preprogrammed time tables. Time for each swim and for each 50-m and 25-m lap were registered by two experienced persons with hand held watches to calculate \(v\) (m·s–1), respectively. The warm-up procedure was standardized to include stretching exercises, 15 min of easy swimming, and a set of two 100-m swims at the starting \(v\) of the test exercise.

#### Blood lactate

Blood samples (25 μl) were taken from hyperemized ear lobes before the first swim, immediately after each of the swims, and 3 and 5 min after the last 200-m swim. Ear lobes were hyperemized (Finalgon®, Boehringer, Ingelheim, Germany) 20 min before the first swim. The samples were analyzed enzymatically (Hitachi U-2000 Spectrophotometer, Tokyo, Japan) for Bla with the Biochemica Boehringer method [4].

#### Heart rate

HR was measured immediately after the cessation of each swim with a automated HR monitor (Polar® Electro PE-3000, Kempele, Finland). The investigator held the receiver when the swimmer arrived. The sampling frequency was set at 5 seconds.

#### Anaerobic threshold (AnT)

Individual graphs for the Bla and HR in function of \(v\) were used to analyze the individual AnT. The point of AnT was estimated according to the \(v\)/Bla relationship using the Dmax method [6]. The method consists of calculating the point that yields the maximal distance from a third order polynomial curve representing

### Table 1 Physical and performance characteristics of the subjects

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Stature (m)</th>
<th>Mass (kg)</th>
<th>(V_{max}) (m·s–1)</th>
<th>Time 200 (s)</th>
<th>F(_{max}) (kg)</th>
<th>CMJ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>24.7</td>
<td>1.79</td>
<td>73.9</td>
<td>1.55</td>
<td>147.9</td>
<td>13.0</td>
</tr>
<tr>
<td>S.D.</td>
<td>5.0</td>
<td>6.7</td>
<td>6.6</td>
<td>0.13</td>
<td>12.8</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Bla as a function of v perpendicular to the line formed by the two end points of the v/Bla curve.

**Percentage velocity (v%)**
The individual graphs for Bla and HR in function of v were changed into percentage scale so that the test maximum represented 100%. Thereafter, Bla and HR values were picked up from each individual graph to represent 80, 85, 90, and 95 from the maximum v and for the two pool lengths.

**Turning benefit (TB)**
Turning skill was estimated by calculating the difference between maximum v preceding the turn and the v corresponding the whole turning distance (7.5 m + turn + 7.5 m = 15 m). This test was executed at maximal effort one day before the first actual test session. The measured difference of v was considered as an index of turning skill. TB was analyzed by underwater video as described earlier by Keskinen and Komi [16] by recording the whole turning distance (7.5 m distance before and after turning) 50 frames·s⁻¹. The camera (Sony® Handycam Video 8, PAL-system, Tokyo, Japan) was put into a water tight container which was attached to a trolley on underwater trails on the side of the 50-m pool, 0.20 m deep, 6.25 m away from the swimmer, and perpendicular to the direction of locomotion. The camera was pushed forward on the trails through the water so that it followed the swimmers with a similar v during the whole turning distance. Turning and swimming v was analyzed by the Kinex method (Kinex®, Tallinn, Estonia) [12].

**Maximum tethered swimming force (MF)**
MF in the water (whole stroke) was measured in tethered swimming according to Keskinen et al. [15]. In this method, the swimmer was attached with a belt and an inflexible rope to a strain gauge force transducer which was further attached to the pool wall 0.50 m above the water surface. The force transducer was connected on-line to a laptop computer including a digitizing card (Texas Instruments®, CODAS®-software, Dallas, TX, USA). The force signal was collected with 100-Hz sampling frequency and analyzed afterwards. The swimmers swam for 10 s in place at maximal intensity. The force curves were smoothed with a gliding average of five points and, thereafter, the mean MF values were picked-up to represent a swimmer’s maximum tethered swimming force.

**Explosive power**
Explosive power of the leg extensor muscles was evaluated on a contact mat (Newtest®, Oulu, Finland) according to the flight time (t) in a single counter movement jump (CMJ). The method uses the following formula to calculate height of a center of gravity in a jump:

\[ h = g \cdot t^2 \cdot 8^{-1} \]

where \( g = 9.81 \text{ m·s}^{-2} \) [18]

**Statistics**
Conventional statistical methods were used for calculating the means, standard deviations (SD), and coefficients of correlation. One-way ANOVA and paired Student’s t-test were used to compare differences between the groups. The level of significance was set at \( p < 0.05 \).

**Results**
The two test series demonstrated similar progression of speed throughout the testing, average v being closely comparable (Fig. 1). Maximum swims were performed significantly faster in the 25-m pool (1.38 ± 0.11 m·s⁻¹ vs. 1.32 ± 0.12 m·s⁻¹; \( p = 0.000 \)), representing a speed difference of 4.5 ± 1.7%. Also, the v at AnT (1.23 ± 0.10 m·s⁻¹ vs. 1.21 ± 0.10 m·s⁻¹) was significantly higher in the 25-m pool than in the 50-m pool.

The averaged v/Bla curves (Fig. 1) demonstrated significantly (\( p = 0.033 - 0.000 \)) higher Bla values for the 50-m pool as compared to the 25-m pool at each v level throughout the testing. The range of percentage difference in Bla between the two different pools was 9.4 – 29.7% (Fig. 1). The maximum Bla was highest in the 50-m pool swimming (8.24 ± 1.55 vs. 7.36 ± 1.47 mmol·l⁻¹; \( p = 0.033 \)). When the comparisons were made between v/Bla in the relative scale (v%), statistically significant (\( p < 0.05 \)) differences in Bla were found only at the maximal v (Fig. 3).

The averaged HR values as seen in Fig. 2 were also significantly (\( p = 0.001 - 0.02 \)) lower in the short course as compared with long-course swims at all submaximal v levels with a mean difference of 7.3 ± 0.7 bpm and with a range of percentage difference of 4.0 – 6.0%. HR after maximum swims was equal between short course and long course pools (172 ± 14 vs. 172 ± 14 bpm; \( p = 0.832 \)). As also shown by Fig. 2, the relationship between HR and v was linear from the start until the end of the two exercise modes. HR at AnT was 152 ± 17 bpm and 154 ± 16 bpm (ns) in the 25- and 50-m pools, respectively. Solely nonsignificant differences in HR could be found between the pool length comparisons when HR was related to the v% (except for the v at 85%) (Fig. 4).

The average TB was 0.12 ± 0.05 m·s⁻¹ (8.1 ± 3.2%) ranging between 0.06 and 0.24 m·s⁻¹, and it correlated positively (\( r = 0.586; p = 0.029 \)) with the difference between the maximal velocities of the short and long course test swims (Fig. 5). TB also correlated significantly with the MF (\( r = 0.750; p = 0.004 \)) and the explosive strength of leg extensor muscles (\( r = 0.554; p = 0.039 \)). The MF (Table 1) was also found to correlate significantly with the turning v (\( r = 0.786; p = 0.002 \)) and with the difference between the maximal v of the short and long course test swims (\( r = 0.586; p = 0.029 \)).
The present observation in maximum intensity swims that there was a significant difference between short and long course swims in Bla (9.4%) and v (4.5%) but not in HR agreed with previous findings [20,30,36]. Lowensteyn et al. [20] suggested that when swimming at comparable intensities and distances in pools of different length, a long course pool will produce 13.8% higher peak Bla than a short course pool. Maximum v was found to be approximately 3.0% higher in the short course, while the post-swimming HR did not differ between the pools. Telford et al. [30] found that post competition maximal Bla was 3.8 mmol · l⁻¹ greater in the 50-m than in the 25-m pool. Wirtz et al. [36] reported that swimmers could swim 50 m faster in the short course pool and the major reason for the better final time was the ability of the swimmers to reach higher v during turning than stroking. It is well approved [2,14, 31 – 33] that higher swimming v produce greater accumulations of Bla and HR. Also, the present observations that Bla and HR differed under two testing conditions, particularly in submaximal v, means that long course swimming was physiologically more strenuous than short course swimming.

The actual concentration of Bla is a result of both invasion of lactate to the blood stream and from the elimination of lactate from the blood. The lactate invasion is produced by diffusion and possible active transport from the working muscles. The elimination of lactate from the blood is a sum effect of further diffusion to the extracellular spaces in other parts of the body, of splitting the lactate by oxidative processes in the musculature, and of resynthesizing to glucose in the liver [3]. We observed that Bla values were lower in the short course swimming at all v levels and the v at the AnT was significantly lower in long course. The obvious explanations for these differences are simply that the frequency of turning may play an important role in regulating physiological response to incremental intermittent swimming exercise. It is a fact that in a 200-m freestyle swim there were four more turns and, therefore, a significantly shorter absolute stroking distance both in each pool length and the whole swim in the short course as compared to long course. In this study, depending on swimming intensity and swimmer’s turning skill, swimmers spent 3 to 6 s of each pool length turning and gliding, with turns defined as the time absent from regular stroking [7]. Thus, during the present 200-m swims in the 25-m pool, swimmers spent about 21 – 42 s turning and gliding while the respective time in the 50-m pool was only 9 – 18 s. It is obvious that each turn with gliding provides relative inactivity for upper body and arm muscles used for regular stroking. The recovery offered by this inactivity may result in decreased muscle lactate production, increased rates of clearance of lactate from the sarcoplasm of these muscles to extracellular fluid, and a possible increased uptake of lactate by metabolically less active muscles [20]. Increased utilization of lactate by inactive muscles during exercise has been reported by Brooks [3]. It was also shown that even a short rest period may allow a partial replenishment of muscle creatine phosphate and myoglobin oxygen stores and a higher rate of oxygenation of hydrogen and lactate ions in exercising muscles may be present [22, 24, 27]. Consequently, a lower Bla for a given v is possible and swimming in a 25-m pool would be less strenuous as compared to 50-m pool swimming.
It should also be noted that exercise specific factors such as the duration of workload and whether the exercise was continuous or discontinuous could affect the Bla response to exercise [9,14,24,27,29,31]. This means that both lactate production and lactate accumulation accelerate as the exercise distance lengthens or resting intervals during exercise bouts shorten. In this study, each 200-m swim in the short course included more than a half less of stroking distance on each pool length before the next turn as compared to the long course. Keskinen et al. [14] found that a slight increase of 0.5 mmol·l⁻¹ in Bla concentration (2 mmol·l⁻¹ level) in the n × 100-m test, 3 mmol·l⁻¹ level in the n × 300-m test, and Bla of 4 mmol·l⁻¹ in the 2 × 400-m test occurred at the same swimming velocity (v), which was considered a common reference point for these three exercise modes and the anaerobic threshold. In the heart rate (HR) vs. v comparison, the HR was higher in the n × 300 m and 2 × 400 m tests than in the n × 100-m test in the same v. In the HR vs. Bla comparison, the HRs were approximately the same at corresponding Bla values in the n × 100-m, n × 300-m, and 2 × 400-m tests. Thus, the observed differences in Bla and HR have been shown to be mainly due to differences in the distances swum during testing trials [14]. Consequently, the results of the tests [11,23,28] were dependent on the time available to produce Bla and HR at a certain swimming speed.

There is also evidence that fixed Bla is strongly influenced by an athlete’s nutritional, training and recovery state and care must be taken to control for such factors when testing an athlete [13,19,21,26,37]. In the present study, these factors were taken into consideration by randomizing the order of testing and by advising the swimmers to eat normally prior to testing sessions.

HR has widely been used as an indicator of training intensity in endurance sports [14]. The present study reports that HR were noted to be significantly higher in the 50-m, as compared to the 25-m pool at each consecutive velocity, except for HR at maximum speeds. This is a natural consequence of the higher strain of the 50-m pool. This is true while Bla levels were also higher in the 50-m pool swimming. It was reported earlier [5,25,32,33] that a high linear relationship exists between HR and swimming v at low to moderate speeds. It should be noted that the HR/v curves are highly specific for each swimmer in exercise testing, and this was also the case in this study. In Fig. 2, we can see a linear relationship between HR/v curves, but it should be remembered that these curves are drawn by mean values of the 11 swimmers. It may be so that the HR/v curves for some swimmers show good linearity at low to high speeds and for some swimmers it may display a significant change in the linear relationship with increasing speeds as suggested by Peyrebrune and Hardy [25] and Treffene et al. [32,33]. Cellini et al. [5] found that for some swimmers the HR/v curves were linear below the AnT and that the line became nonlinear after the intensity exceeded AnT.

The HR response is easily altered by a number of environmental (ambient temperature), dietary (time since last meal, level of body hydration), and behavioral (previous activity) factors [1]. Also, anxiety, fear, excitement, and related emotional stresses may cause a marked elevation in HR at low to moderate workloads [8,10]. The heavier the work rate, the less pronounced the nervous effect will be on the HR. It was reported [8,10] that the intraindividual day-to-day HR variability was 8%, and as the intensity of exercise increased, the variation in the HR decreased to approximately 2% (HR > 165 bpm). In the present study, the daily variation of HR was eliminated by randomizing the order of testing. While no differences were found after the last repetition, both the 25-m and 50-m pool swims were performed with a maximal effort, the number of turns having no effect on the final values.

One of the interesting findings of this study was that Bla and HR curves for the short and long course swims were nearly identical when the curves were drawn in function of v% from the test maximum (see Fig. 3 and 4) but were very different when the curves were drawn in absolute v scale (see Fig. 1 and 2). Thus, this is a good demonstration that in order to standardize the testing procedures and training speeds the pool length is of major importance. However, the physiological reaction to the work increment is similar in the two exercise conditions regardless of the pool length.

The present study observed several significant relationships between the TB and other variables. Firstly, there was a significant relationship between TB during short maximum swims around the turning wall and the maximal v difference between the short and long pools. Secondly, there was a significant relationship between TB and MF. Finally, significant relationship also existed between the TB and explosive power of the leg extensor muscles. These observations mean that the more the swimmers were able to increase v during the turns, the more pronounced increases in swimming speed they could gain during the course of the 25-m pool testing as compared to the 50-m pool. This was also analogical to better competition results in short course swimming [30,36]. It is obvious that technically skilled swimmers gain more advantage from the turns than their less skilled counterparts (see Fig. 5). These suggestions are in good agreement with the results of Wirtz et al. [36] and Wakayoshi et al. [34] who found that v was significantly altered during turning phase than stroking phase, and faster swimmers gained more advantage from the turns than slower swimmers [34]. Men having a better potential for muscular force production both on land and in the water gained more advantage from the turns in the 25-m pool than women, pointing out that muscular force has a major influence on the swimming performance [15].

While the training in the 25-m pool seems less strenuous than in the 50-m pool, the swimmers that usually use short course training should also train in the 50-m pools in order to get more accustomed to more strenuous competitive circumstances. It is supposed by Lowensteyn et al. [20] that swimmers trained in short course pools are at a clear disadvantage when competing in long course pools, as they may be unaccustomed to higher muscle and systemic lactate levels generated in long course pools and would be more susceptible to lactate related muscle fatigue. On the other hand, according to previous studies [17,36], training in the 25-m pool may help swimmers to develop their stroking patterns to fit with higher swimming v while the short course swimming allows a better swimming v with a more efficient stroking as seen from the longer stroke length during 25-m pool swimming.
Effects of pool length on Bla and HR, especially at the speed of AnT should be taken into account when performing exercise testing for the aquatic athletes. The present data suggest that in order to understand the conditioning process taking place during continuous training, the physiological testing should be performed in conditions similar to their daily training. Thus, coaches that utilize Bla and HR measurements to design optimal training intensities for their swimmers are encouraged to establish individualized profiles separately for both 25-m and 50-m pools to avoid systematic errors in training intensity.

We conclude that pool length influences Bla and HR when an exercise is performed at constant intensity and distance. A shorter absolute stroking distance in the 25-m pool swimming as compared to 50-m pool and the extra turns in connection with a good ability for turning were the major factors to the observed differences between the two testing conditions. Thus, the short course training could be seen to allow less strenuous swimming as compared with long course swims. The pool length must be taken into consideration when comparing swim performances in pools of different length, and when planning training strategies based upon targeting of specific energy systems, Bla and HR. High potential for muscular force production in both on land and in the water, when complemented with high swimming skill, will add up to successful performance, especially in the short course swimming.

References

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