



Relationship between swimming speed and physiological and perceptual responses in skins race

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ABSTRACT

Purpose: This study investigated the relationships between swimming speed and physiological and perceptual responses in a skins race, in which a maximum of three races are repeated with a rest in between each round. **Methods:** The study measured the physiological responses in terms of the heart rate, maximal oxygen uptake ($\dot{V}O_2$ max), and oxygen debt (O_2 debt) and examined the perceived exertion to determine the perceptual response. Specifically, it measured the swimming speed and blood lactate (Bla) levels of seven male collegiate swimmers in three rounds of 50 m freestyle, which simulated skins race. It also conducted a bicycle ergometer test to measure their $\dot{V}O_2$ max and O_2 debt. **Results:** The results showed a significant association between swimming speed and Bla. In other words, the study found a significant association between swimming speed and glycolysis during the skins race. However, it did not find a significant association between swimming speed and $\dot{V}O_2$ max or/and O_2 debt. **Conclusion:** Hence, it concluded that a swimmer's skill level is related to the swimmer's speed in the skins race. These findings provide an understanding of the physiological parameters that effect performance in high-intensity sports.

Keywords: Performance analysis of sport, Physical conditioning, Skins race, Swimming Speed, Blood lactate, Maximal oxygen uptake, Oxygen debt.

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INTRODUCTION

Established in 2019, the International Swimming League (ISL) was a new initiative in the domain of professional swimming. This competition has two formats—team competition and skins race. In the team competition, teams compete for points to win. The team competition comprises 10 teams, 11 preliminary league matches, 6 playoff matches, and a final match. Four teams compete in each match, and two representatives are selected from each team for each race. Teams receive points for each race, which determines the winner of the team competition. The points are distributed in descending order from the first-place finisher to the eighth-place finisher. However, there are several rules for earning points, and the points awarded are not always earned. One of these rules is referred to as the jackpot time rule. This rule applies to the first-place finishers players of a race who outdo their opponents by a time margin exceeding the jackpot time. The points distributed to the competitors of the race in question are awarded to the first-place finisher. Conversely, the cutoff time rule applies to players who fail to finish the race within the minimum cutoff time. These athletes lose their points and subject their team to penalty. These unique rules make it important for swimmers to consider tactics at ISL.

Concerning the skins race, it is a relatively new event. It consists of eight swimmers from four teams, each having two representatives. It differs from the team competition in that it involves winning three 50 m races. Half of the swimmers are eliminated after each 50 m round, and the winner is decided after the third round. The interval between each round is set to 3 min. For the first time in the history of competitive swimming, the winner-takes-all system of the ISL allows players to take all the points accumulated in each of the three rounds. This is different from the conventional swimming competitions where the points can be collected once per race. However, in the ISL's skins race, swimmers can swim a maximum of three rounds and earn points at the end of each round. As a result, the ISL skins race swimmers can earn points thrice more than the swimmers at other events and have a greater impact on the team competition. Given this, the swimmers can contribute to the team competition by earning high points in the skins race competition. However, a swimmer should possess both endurance and speed to earn high points, and thereby realize the winner-takes-all benefit of the skins race.

There are several studies on swimming speed and endurance. Kurokawa et al. (1985) reported that maximal oxygen uptake ($\dot{V}O_2 \text{ max}$) and maximal oxygen debt ($O_2 \text{ debt}$) influence performance outcomes. However, this is based on the assumption that the winner is determined by a single swim. Under such circumstances, $\dot{V}O_2 \text{ max}$ and $O_2 \text{ debt}$ have been found to be related to swimming speed, but the effects of these parameters have been unclear in competitions such as skin races, in which multiple races are repeated within a short span of time. In this context, this study investigates the relationships between swimming speed and physiological and perceptual responses in the skins race. In this race, a maximum of three races are repeated with a rest in between each round.

METHOD

Subjects

The study sampled seven healthy male collegiate swimmers (age: 19.6 ± 1.4 years; height: 170.1 ± 4.6 cm; and weight: 62.0 ± 7.3 kg), who held their best record in 50 m freestyle (26.9 ± 1.8 sec). They trained in the water and on land about thrice/week and twice/week, respectively. The subjects' $\dot{V}O_2 \text{ max}$, $\dot{V}O_2 \text{ max/wt}$, $O_2 \text{ debt}$, and $O_2 \text{ debt/wt}$ were 3355.7 ± 378.4 ml/min, 54.5 ± 6.2 ml/min/kg, 5715.7 ± 4100 ml, and 91.9 ± 62.8 ml/kg, respectively.

Procedure

Skins race, $\dot{V}O_2$ max, and O_2 debt were measured on separate days. Skins races were conducted in a long-distance swimming pool. Subjects completed three rounds of 50 m crawl in accordance with the skins race competition. Using a stopwatch, the study manually measured the swim time for each round. After a 50 m cool-down period of 3 min, the swimmers proceeded to the next round.

The study conducted a bicycle ergometer (i.e., Power Max-VII, Combi) test to measure $\dot{V}O_2$ max and O_2 debt (Aerobike 330, Combi). The ergometer works as an exercise load device. Concerning $\dot{V}O_2$ max, after 30 min of seated rest, the subjects performed at 60 rpm and 0 W for 3 min; the load was increased by 50 W every 3 min until the subjects were exhausted. Concerning the O_2 debt, after 30 min of seated rest, the subjects performed full power pedaling work at a load equal to 7.5% of their body weight for 30 s. The study measured the oxygen uptake during the recovery period, after pedaling.

Measurement items

At the start phase of the skins race, the subjects positioned themselves on a starting block with a back plate (Seiko). The interval between the starts was 3 min. The study measured the swimming speed, heart rate (HR) (A300, polar), and blood lactate concentration (lactate pro2, Arkray) at rest, after the warming-up, and 1 min after each round for 5 times during the skins race. It also measured the post-race subjective exercise intensity (ratings of perceived exertion: RPE).

The study used a wearable exhaled gas measurement device to measure $\dot{V}O_2$ max (Pnoe, Endo Medical, Inc.). Specifically, the study continuously measured $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE, VT, BF, FEO₂, and FECO₂; $\dot{V}O_2$ max was the maximum value of the average values per min. The subjects were asked to indicate their HR during exercise and RPE from a table, which was shown to the subjects 1 min before the load change.

The study used a wearable exhaled gas analyzer to measure the O_2 debt (Pnoe, Endo Medical, Inc.). The study obtained the O_2 debt by subtracting the subjects' resting $\dot{V}O_2$ from the sum of $\dot{V}O_2$ at 40 min, immediately after full strength pedaling work for 30 s at a load of 7.5% of the body weight. Resting $\dot{V}O_2$ denoted the sum of the last 10 min of the 40 min of the $\dot{V}O_2$ work, after the exercise.

Statistical treatment

The study expressed the results as mean \pm standard deviation and adopted a significance level of less than 5%. It calculated the Pearson's product-rate correlation coefficient for correlations.

RESULTS

Table 1 shows swimming speed, HRmax, RPE, and Bla for the three rounds of the skins race. Swimming speed was highest in round one, which decreased progressively with each round; however, HRmax, RPE, and Bla increased with rounds.

Table 2 shows the correlation matrix between swimming speed and Bla , for each round. Swimming speed in each round was significantly related to swimming speed and Bla in the next round.

Table 1. Swimming speed, HRmax, RPE, and Bla for the three rounds of skins race.

Indices		1R	2R	3R
Speed (m/s)	Mean ± SD	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.2
HRmax (beats/min)	Mean ± SD	170.3 ± 8.0	174.3 ± 8.7	175.0 ± 7.4
RPE	Mean ± SD	14.0 ± 1.3	15.7 ± 1.0	17.4 ± 0.9
Bla (mmol)	Mean ± SD	7.4 ± 2.7	12.9 ± 4.7	15.7 ± 4.2

Table 2. Correlation matrix between swimming speed and Bla for each round.

	1	2	3	4	5
1. Swimming speed for round 1					
2. Swimming speed for round 2	.981**				
3. Swimming speed for round 3	.971**	.993**			
4. Bla for round 1	.695	.641	.626		
5. Bla for round 2	.836*	.857*	.830*	.593	
6. Bla for round 3	.905**	.863*	.838*	.625	.923**

Note. **: $p < .01$, *: $p < .05$.

Table 3 shows the relationship matrix between swimming speed, $\dot{V}O_2$ max ($\dot{V}O_2$ max/wt), O_2 debt (O_2 debt/wt), and $\dot{V}O_2$ max+ O_2 debt ($\dot{V}O_2$ max/wt+ O_2 debt/wt). $\dot{V}O_2$ max was significantly associated with O_2 debt (O_2 debt/wt) and $\dot{V}O_2$ max+ O_2 debt ($\dot{V}O_2$ max/wt+ O_2 debt/wt). O_2 debt (O_2 debt/wt) was significantly associated with $\dot{V}O_2$ max/wt+ O_2 debt/wt ($\dot{V}O_2$ max/wt+ O_2 debt/wt).

Table 3. Relationship matrix between $\dot{V}O_2$ max, $\dot{V}O_2$ max/wt, O_2 debt, O_2 debt/wt, $\dot{V}O_2$ max+ O_2 debt, $\dot{V}O_2$ max/wt+ O_2 debt/wt and Swimming Speed.

	1	2	3	4	5	6	7	8
1. $\dot{V}O_2$ max								
2. $\dot{V}O_2$ max/wt	.473							
3. O_2 debt	.812*	.607						
4. O_2 debt/wt	.776*	.675	.994**					
5. $\dot{V}O_2$ max+ O_2 debt	.840*	.604	.999**	.990**				
6. $\dot{V}O_2$ max/wt+ O_2 debt/wt	.771*	.724	.986**	.998**	.982**			
7. Swimming speed for round 1	.165	-.580	.096	.033	.104	-.025		
8. Swimming speed for round 2	.272	-.443	.174	.119	.185	.068	.981**	
9. Swimming speed for round 3	.309	-.382	.268	.216	.276	.164	.971**	.993**

Note. **: $p < .01$, *: $p < .05$.

DISCUSSION

This study examined the relationships between swimming speed and physiological and perceptual responses during skin races. To this end, the study sampled male collegiate swimmers, whose best record in 50 m freestyle varied widely. Specifically, the study found a difference of 5.4 s between the fastest and slowest swimmers. This implies a large difference in the swimming technique of the subjects.

Concerning their anaerobic capacity, the O₂ debt (5.72 l and 91.9 ml/kg, respectively) of the subjects were 11–34% lower than those of the leading male swimmers in Europe and the United States (8.69 l and 118 ml/kg) (Cureton 1951), male university swimmers in Europe and the United States (7.75 l and 103 ml/kg) (Shephard et al. 1974), Japanese male university group (8.67 l and 131.1 ml/kg) (Kurokawa et al. 1985), and male elite swimmers (8.05 l and 118.6 ml/kg) (Kurokawa et al. 1985).

Concerning their anaerobic capacity, $\dot{V}O_2$ max were 3.36 l and 54.5 ml/kg/min, which were 19–33% lower than those of the top male swimmers (4.14–5.05 l/min) (Holmer 1972; Holmer et al. 1974; Magel and Faulkner 1967). These values were 0–21% lower than those of the male university swimmers (3.36–4.26 l/min) (Dixon and Faulkner 1971; Holmer 1972; McArdle, et al. 1971), 6–17% lower than those of the Japanese male elite swimmers (4.04 l/min, 58.2 ml/kg/min) (Kurokawa et al. 1985), and almost equal (1–6%) to those of the male university students (3.63 l/min, 54.8 ml/kg) (Kurokawa et al. 1985). In terms of $\dot{V}O_2$ max/wt, the subjects were almost equal to their counterparts in universities and elite groups. Thus, although the subjects had a lower anaerobic energy supply capacity than that of the high-level swimmers, their aerobic energy supply capacity was approximately at the same level.

This study found a significantly high correlation coefficient between swimming speed and Bla in skins race. This relationship strengthened as the players progressed to the subsequent rounds. In this regard, Sakai et al. (1999) showed that, among the indices of the aerobic energy-producing capacity, submaximal work capacity had a higher correlation with intermittent high-power exercise than that of $\dot{V}O_2$ max. It must be noted that the submaximal work capacity does not increase the Bla of individuals exercising under constant load conditions. However, the energy-producing capacity of the lactic acid system did not have a significant correlation with an intermittent high-power exercise. This also implies that the former does not share a significant relationship with the ability to maintain swimming speed in a high-intensity intermittent exercise such as the skins race. However, Sakai et al. (1999) examined a high-intensity exercise as a 7-second full-power exercise, which is shorter than the skins race. Skins race is a short-duration, high-intensity, intermittent exercise that takes approximately 30 s to complete. In this regard, Hatta (2009) pointed out that glucose breakdown can contribute toward high lactate levels during exercise. Studies show that glucose breakdown is key to energy supply during high-intensity and short-duration exercises. Given that Bla is an index of energy supply capacity in glycolysis, an increase in Bla in the skins race indicates that the subjects' ability to maintain swimming speed in the skins race (high-intensity intermittent exercise of about 30 s performed every 3 min) is related to the lactate energy production capacity. Thus, the results suggest that the ability to maintain swimming speed during the skins race is mainly related to the ability to produce lactate energy. This ability becomes more pronounced with every subsequent round.

Concerning the aerobic energy-producing capacity, the results showed that swimming speed in the skins race does not share a significant correlation with the aerobic energy-producing capacity ($\dot{V}O_2$ max, $\dot{V}O_2$ max/wt) or anaerobic energy-producing capacity (O₂ debt, O₂ debt/wt). However, the results showed a significant association between the body mass index (BMI) and swimming speed in each round. In this regard, in 100–400 m swimming, studies have reported a significant association between swimming speed and the absolute and relative values of $\dot{V}O_2$ max, especially the absolute values (Kurokawa et al. 1995). This can be attributed to the fact that, since buoyancy plays a role in swimming, there is little need to support body weight against gravity (Kurokawa et al. 1985). Moreover, the body surface area (which is closely related to body weight) does not affect individual differences in body water resistance (Miyashita, 1970). Since skins racing is an underwater exercise, body weight is not considered a disadvantage, but an advantage, in this

competition The subjects had a relatively large muscle mass because of their regular training regimen. This muscle mass increased their BMI, thereby significantly influencing their swimming speed.

Regarding $\dot{V}O_2$ max, Yamamoto and Kanehisa (1990) showed that the relationship with $\dot{V}O_2$ max was stronger during intermittent and sustained full-strength exercise performed for short periods of time. This is because prolonged exercise stimulates the supply of both anaerobic and aerobic energy. In other words, the energy expended during exercise is repeatedly recovered by the aerobic activity during rest and used for the next exercise. The same might be true for high-intensity, intermittent exercise such as the skins race. However, this study did not find significant differences in the aerobic or anaerobic energy supply capacity of the subjects. The effect of the aerobic energy supply capacity on recovery during the interval was also not found significant. Hence, the study deduced that the differences in the subjects' swimming skills (as captured by subjects' best records of 50 m freestyle) affected the swimming speed of the subjects in the first round of the skins race. This finding suggests that the swimming speed in the first round was significantly associated with the swimming speed in the second round, and the swimming speed in the second round was significantly associated with the swimming speed in the third round.

Given that the skins race is a high-intensity, short-duration intermittent exercise, both the lactic- and aerobic energy supply capacities were expected to play role in the skins race as a. However, this study did not find significant differences in the aerobic energy supply capacity or anaerobic energy supply capacity. Bla was also significantly associated with swimming speed in the skins race. Hence, this study concluded that there is a significant relationship between the resulting differences in skill level and the swimming speed in the skins race.

AUTHOR CONTRIBUTIONS

Conceptualization: Y. Tsukahara and T. Ueda. Data curation: Y. Tsukahara. Formal analysis: Y. Tsukahara and T. Ueda. Investigation: Y. Tsukahara. Methodology: Y. Tsukahara and T. Ueda. Project administration: T. Ueda. Resources: T. Ueda. Supervision: T. Ueda. Validation: T. Ueda. Visualization: T. Ueda. Writing – original draft: Y. Tsukahara. Writing – review & editing: T. Ueda.

SUPPORTING AGENCIES

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DISCLOSURE STATEMENT

We communicated the intent and methods of this study to the subjects. We also obtained informed consent. This research was also approved by the research ethics committee of the Graduate School of Education, Hiroshima University. The committee gave a reference number HR-ES-000338.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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