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TOPIC REPORT:

Swimming Economy: How to standardize the data to compare swimming proficiency

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Abstract

The influence of body size upon oxygen consumption (VO2) during front crawl, back crawl and breaststroke swimming is illustrated. Use of VO2 in l/min to compare swimming economy in competitive swimmers of different sizes must therefore be made with caution. A method of adjusting VO2 measured in liters per minute to account for body size, as represented by total body mass, is presented. This method produces weight-adjusted scores which reflect swimming proficiency, and standardizes the data to allow for comparisons of economy amongst different swimmers. A classification system of weight-adjusted VO2 scores by the method of partial covariance (5) is also presented in order to evaluate the economy of swimmers competing at regional to international levels.

Introduction

Sport scientists have become increasingly aware that while qualitative descriptions of swimming technique are necessary in the coaching and evaluation of competitive swimmers, an attempt must also be made to describe stroke technique quantitatively, that is, using a scientific or mathematical approach. Several biomechanical or physiological methods may be used to evaluate the efficiency of swimming mechanics in this manner. The measurement of oxygen uptake (VO2) during swimming at different speeds has become an increasingly popular physiological technique, and describes the “economy” of swimming for each particular athlete. Oxygen uptake is typically expressed in liters per minute, but as body size affects this measure to a large extent (3, 4, 9) this may not be the best method to describe how economically a swimmer moves with respect to technique alone. What is required, then, are individual, weight-adjusted scores that are maximally related to the observed oxygen uptake, yet which are also independent of body mass.

The initial aim of this paper is to illustrate the influence of body size upon the oxygen cost of swimming by presenting data from regional to international level competitive swimmers. The mathematical equations relating body mass and VO2 during front crawl, back crawl, and breaststroke swimming, are also described. Secondly, an appropriate method for the expression of oxygen uptake so as to account for the effects of body mass in measures of swimming economy for each stroke is proposed.

Oxygen Uptake vs Body Mass

The oxygen demand of swimming over a wide range of velocities is clearly affected by a swimmer’s total body mass (Mb) (Figure 1a). The increase in the oxygen requirements correlates with the increase in resistive forces, termed drag. Drag is dependent on three major factors plus a dimensionless constant that take into account the characteristics of the body and the fluid medium. These are 1) swimming velocity, 2) density and viscosity of the water, 3) body size and 4) the drag coefficient, a term dependent on the peculiarities of water flow around the body. The formula conventionally used to estimate drag is:
where \( p \) = water density, \( S \) = size variable, e.g. frontal area, surface area, etc., \( V \) = velocity, and \( C_d \) = drag coefficient.

Because it enters directly into the equation above, body size has a strong influence on total drag encountered by a swimmer. For the same speed, water resistance in a big swimmer is much greater than in a small swimmer; therefore, the amount of work done by the big swimmer is greater. By lieu of the relationship between metabolic power and work, size will affect \( \text{VO}_{2} \) (7).

The oxygen cost, at one specific velocity, for front crawl, back crawl and breaststroke swimming for athletes of different size is the greater the swimmer’s mass, the greater is the oxygen uptake. However, for any given increase in body mass, there is not a proportional increase in \( \text{VO}_{2} \), i.e., the oxygen demand does not scale to \( \text{Mb}^{1.0} \). In fact the scaling factors* are, 0.76, 0.55, 0.87 for front crawl \( (v = 1.3 \text{m/s}) \), backstroke \( (v = 1.1 \text{m/s}) \) and breaststroke \( (v = 0.9 \text{m/s}) \), respectively (1,9,10). Therefore, simply dividing the oxygen uptake \( (1/\text{min}) \) by a swimmer’s mass, i.e., expressing \( \text{VO}_{2} \) relative to body size \( (\text{ml. kg}^{-1}.\text{min}^{-1}) \), is obviously misleading when comparing swimmers of different size. Such a ratio, \( \text{VO}_{2}/\text{Mb} \), produces a bias in favor of bigger swimmers (Figure 1b).

Not only is the expression of \( \text{VO}_{2} \) per kilogram body weight somewhat erroneous, but its use in statistical analysis can also be misleading (6,11). When this ratio is related to other variables, spurious correlation of indices may occur. The degree of spuriousness resulting from the use of the ratio depends upon the extent of the correlation between \( \text{VO}_{2} \) and body mass, and the departure of the ratio standard (equation) from the true regression standard (11).

What is required then, is a method of obtaining individual weight-adjusted scores that will be maximally related to the observed oxygen uptake, yet correlate zero with body mass. Such scores may be obtained by using the method of partial covariance as suggested by the mean group \( \text{VO}_{2} \) for the same stroke and speed of swimming (Table 1); \( \text{VO}_{2obs} \) \( (1/\text{min}) \) is the observed \( \text{VO}_{2} \) for a particular swimmer; and \( \text{VO}_{2pred} \) \( (1/\text{min}) \) is the predicted \( \text{VO}_{2} \) for that same swimmer, based upon his/her body mass (Table 2).

### Applications

WA-\( \text{VO}_{2} \) is thus an expression of the economy of a given swimming stroke which may be compared between

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*To calculate the scaling factor, the data is put on log-log coordinates and the least squares regression is described by the equation: \( \log \text{VO}_{2} = \log a + b \log \text{Mb} \) where \( a \) is a constant, \( b \) is the scaling factor or slope, and \( \text{Mb} \) is the body mass.
athletes of different sizes. As we have used data based upon the observations of the swimmers described in Table 1, use of the given group mean VO2 and equations for VO2pred in obtaining WA-VO2 is limited to swimmers who fall within the same range of body mass and height. Swimmers must also be tested at the same velocities as used in our examples. However, if a large group (n = 30) of swimmers are to be tested, the same procedure of relating VO2 to body mass, and obtaining an equation of VO2pred, as well as a mean VO2, may be used for measures of VO2 at any velocity. Athletes who require a greater WA-VO2 to swim at the same speed as others are uneconomical, likely as a result of a less proficient technique (8).

Table 3 shows some actual performance times and WA-VO2 scores of swimmers for each of front crawl, back crawl and breaststroke. While it is not always the case that the fastest swimmer will be the most economical, WA-VO2 does reflect the quality of a swimmer's stroke mechanics, and is thus an important factor in relation to performance (1,2,10). Generally, good economy is an important factor for 400m and distance swimmers (2,4). It is also related to 200m race performances, and, to a lesser degree, to sprinting (100m) (10). Economy may also be a more discriminating measurement in front crawl and backstroke swimmers than in breaststrokers, where other factors, such as muscular power, may play a more important role.

Conclusions
Measurement of the oxygen uptake of swimmers at submaximal velocities, and adjusting VO2 for body
mass, provides a means of quantitatively assessing a swimmer's technical proficiency. This score provides information which can be used to supplement a coach's subjective judgements with regards to a swimmer's stroke mechanics. Economy expressed in this manner is also indicative of performance ability, and thus is a valuable measure for use in the training and testing of competitive swimmers.

Table 3. Examples of actual race performance times, WA-VO2, and economy classifications for swimmers in each stroke.

<table>
<thead>
<tr>
<th>Stroke</th>
<th>200m Performance (min:sec)</th>
<th>WA-VO2 (l/min)</th>
<th>Economy Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Crawl</td>
<td>1:50</td>
<td>2.72</td>
<td>Excellent</td>
</tr>
<tr>
<td>(200m)</td>
<td>1:58</td>
<td>3.00</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>2:03</td>
<td>3.18</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>2:12</td>
<td>3.38</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>2:17</td>
<td>3.63</td>
<td>Poor</td>
</tr>
<tr>
<td>Back Crawl</td>
<td>2:03</td>
<td>1.55</td>
<td>Excellent</td>
</tr>
<tr>
<td>(200m)</td>
<td>2:12</td>
<td>2.33</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>2:15</td>
<td>2.48</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>2:17</td>
<td>2.76</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>2:25</td>
<td>2.99</td>
<td>Average</td>
</tr>
<tr>
<td>Breaststroke</td>
<td>2:38</td>
<td>2.35</td>
<td>Good</td>
</tr>
<tr>
<td>(200m)</td>
<td>2:39</td>
<td>2.51</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>2:48</td>
<td>2.64</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>2:54</td>
<td>2.87</td>
<td>Poor</td>
</tr>
<tr>
<td></td>
<td>3:00</td>
<td>2.85</td>
<td>Poor</td>
</tr>
</tbody>
</table>

References
The Effect of Shaving Body Hair on the Physiological Cost of Freestyle Swimming

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Abstract

The purpose of this study was to determine if shaving of body hair would have an effect on the physiological cost of standard swimming velocities. Physiological effort required to swim at a given velocity was assessed using determinations of blood lactate concentration 2 min after each of four 200 yard freestyle swims. Six subjects volunteered and were asked to swim four 200's with 15 min rest between each and reducing their time by roughly 10 sec on each consecutive swim. On the next day, subjects shaved their body hair from arms, legs and exposed torso and repeated this swimming protocol. Blood lactate accumulation at a submaximal speed of 1.08 m/sec was significantly reduced by an average of 28% by shaving. Blood lactate accumulation at a maximal swimming speed of 1.30 m/sec was significantly reduced by an average of 23%. This much change in the physiological cost of submaximal and maximal swimming speeds is nearly as great as that resulting from a season of collegiate swimming training. It was concluded that there is indeed a physical benefit to shaving-down (most likely a reduction in body drag) and that the benefits are not solely due to a psychological response.

Since the late 1950's competitive swimmers have prepared for major competition by removing the hair from their arms, legs, torso and sometimes also from their head on the day of competition. It is likely that only a very small percentage of American and world records over the past 20 years have been set by swimmers who were unshaved. Perhaps following the lead of their elite counterparts, even novice level swimmers will shave for regional and State championships. In addition, many coaches on the collegiate level advise their swimmers to shave for an early season competition so they can meet qualifying standards for championship meets held later in the season.

Despite the obvious importance that competitive swimmers have placed on shaving down, there does not exist any published literature which either supports or refutes the notion that this technique can enhance the performance of competitive swimmers. It is therefore unknown whether this practice is effective in reducing body drag enough to make a difference in performance or if it persists simply out of convention. In 1968, Counsilman (3), stated that there is no valid evidence to substantiate the theory that shaving down can decrease skin resistance enough to influence performance and that any improvements in performance thought to be due to shaving were likely normal improvements resulting from training or from the psychological effect the shaving might induce in the swimmer. He further speculated that if there is an advantage to shaving, it may be that it "increases the swimmer's sensitivity to the feel or pressure of the water and consequently improves his coordination."

In 1933, Karpovich determined that water resistance encountered by the body during passive towing is proportional to the square of velocity, indicating that overcoming resistance at high speeds would require energy expenditure to increase exponentially (6). An exponential increase in energy expenditure as a function of velocity was later demonstrated by Holmer (4) who attributed this relationship to the effect of body drag.
Other studies sought to determine to what extent certain anthropometric characteristics contributed to body drag (1,2,5,8). Using a multiple regression analysis, Clarys showed that passive drag was most closely related to the greatest cross-sectional diameter of the swimmer but had a non-significant relationship with total body surface area (1). This should not, however, be taken to mean that other anthropometric characteristics are not significant contributors to body drag. Observations on body drag of female swimmers, for instance, have shown that females experience less body drag than males at any given velocity of towing or of free swimming (9). In part this difference was due to differences in body size. Such differences were reduced but not abolished by correcting drag measurements for body surface area and body density. It has also been shown that body drag can be reduced independent of changes in cross-sectional diameter by measuring drag on female swimmers with and without swimming suits (10). These studies showed that a typical female competitive swimming suit adds roughly 9% to body drag across all velocities.

Since body drag provides the primary component of external workload during swimming, reductions in body drag would be expected to reduce the metabolic demand of any given intensity. Thus, if shaving the hair from the body reduces drag, blood lactic acid accumulation at a given velocity should decrease. It was therefore the purpose of this study to assess the effect of denuding the skin of hair on the physiological responses to submaximal and maximal swimming velocities.

Methods

Four males and two females aged 20-34 years volunteered as subjects for this study. None of the subjects was engaged in swimming training at the time of the experiments and all but one were competitive swimmers (1 month to 10 years in the past.) Each of the subjects was fully informed of the possible risks and benefits of their participation in the study before giving their written consent.

Each subject was asked to perform four 200-yard freestyle swims with 15 min rest between each on two consecutive days. On the first day, the subject was asked to swim the first 200 at a mild pace, the second 200 at medium pace, the third 200 at a moderately hard pace and the fourth 200 at an all-out pace. In addition, the subjects were advised to decrease their time by roughly 10 sec on each consecutive 200. The swims were timed from the instant the feet broke contact with the starting wall until the hand touched the finish wall. At the same time on the second day, after shaving all the hair from the arms, legs and exposed torso, the subjects performed the same protocol and were asked to duplicate the times recorded for the first three 200's from the previous day. For the fourth 200, the subjects were asked to exert an all-out effort. Two min after each of the swims, a 20 microliter fingertip blood sample was obtained and immediately deproteinized in perchloric acid. The blood samples were later centrifuged and analyzed for lactic acid concentration using an enzymatic spectrophotometric method (7). All of the blood samples for each subject were analyzed in the same assay in order to eliminate any inter-assay variability.

Because the subjects could not exactly duplicate their trial times of the first day, we used a regression of log lactate on velocity to compare the blood lactate responses at standardized speeds. Briefly, this procedure requires that blood lactate concentration be converted to common logarithm and then treating the relationship between log lactate and velocity with linear regression analysis followed by prediction of lactate concentration at standard speeds for each subject in each condition. An example of how such a plot looks is shown in Fig. 1. We have chosen the log lactate technique over others because we have found that this usually gives us the best curve fit and least error in prediction. The correlation coefficients for these trials ranged between 0.91 to 0.99.

The regression equations were used to determine blood lactate at speeds of 1.08 ± 0.06 m/sec and 1.30 ± 0.06 m/sec both pre- and post-shave. These velocities were chosen for comparison because the former corresponds to the pre-shave velocity at a blood lactate of 4 mM and the latter represents the maximum pre-shave velocity. Group means for blood lactate at these velocities were compared between pre- and post-shave.

![Figure 1. Sample graph of velocity vs. blood lactate concentration taken before and after shaving-down. V1 indicates velocity corresponding to 4mM on pre-shave trial which was then compared to predicted blood lactate at this velocity post-shave. V2 indicates fastest velocity of pre-shave trial which was used as reference velocity to compare blood lactate pre- and post-shave.](image-url)
using repeated measures ANOVA. The greatest velocity achieved pre-shave was compared with that of post-shave using a paired t-test. Likewise, blood lactate after the fastest pre-shave swim and post-shave were compared. The null hypothesis was rejected when $P < 0.05$. All data are reported as mean ± SE.

Results

Performance speeds and blood lactate concentrations for the pre-shave and post-shave conditions are shown in Table 1. In spite of our instruction to the subjects to swim the same speed on the second day (shaved) for the first three 200's, the velocities were significantly faster. Blood lactate concentration was, however, significantly lower after the first three swims in the shaved trial. There was no significant difference in lactate concentration after the fourth swim between pre-shave and post-shave in spite of the fact that the subjects swam significantly faster after shaving.

At the pre-shave velocity corresponding to a blood lactate concentration of 4mM (1.08 ± 0.06 m/sec), blood lactate was significantly lower post-shave (2.90 ± 0.29 mM) and represents an average decrease in blood lactate at this velocity of 28 ± 7%. At the pre-shave maximum velocity of 1.30 ± 0.06 m/sec, blood lactate was also observed to be significantly lower post-shave (7.99 ± 0.47 mM) than pre-shave (10.56 ± 0.84 mM). The group mean percentage decrease in lactate at this speed was 23 ± 3%. These data are shown in Fig. 2.

A group mean lactate/velocity profile for both pre-shave and post-shave is shown in Fig. 3 and shows a significant rightward shift in the profile with the magnitude of shift appearing roughly equal at all speeds.

Discussion

The major finding of this study is that shaving the hair from arms, legs and torso substantially reduced the physiological cost (as judged by accumulation of blood lactate) of both submaximal and maximal freestyle swimming speeds. The reduction in blood lactate accumulation at standard speeds is generally taken as evidence of 1) improved aerobic fitness which either increases lactate clearance or reduces lactate production, 2) improved mechanical efficiency, or 3) muscle glycogen depletion as a result of heavy training. Since these swimmers were not engaged in swimming training at the time of this experiment and since the trials were conducted on consecutive days, it is very unlikely that

<table>
<thead>
<tr>
<th>Velocity (m/sec)</th>
<th>1.07</th>
<th>1.16</th>
<th>1.24</th>
<th>1.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE Lactate (mM)</td>
<td>4.16</td>
<td>5.68</td>
<td>7.56</td>
<td>10.56</td>
</tr>
<tr>
<td>POST Lactate (mM)</td>
<td>3.72</td>
<td>4.55</td>
<td>7.06</td>
<td>11.20</td>
</tr>
</tbody>
</table>

Figure 3. Group mean blood lactate/velocity profiles for four 200 yard freestyle swims before and after shaving-down...
changes in aerobic fitness or muscle glycogen depletion could account for the changes in blood lactate that were observed. We have also found that when this protocol is used on consecutive days without shaving, the blood lactate accumulation at standard speeds is identical between days. For these reasons, we favor a reduced physiological cost as the explanation for decreased blood lactate accumulation observed in this study.

The magnitude of reduction in blood lactate accumulation observed in this study is quite substantial when compared with that normally associated with training. Unfortunately, little literature exists regarding how much of a shift in the lactate/velocity profile we can expect from a season of training. However, we have used these profiles to evaluate the progress made in training of collegiate swimmers. Over the past 4 years we have observed that during a collegiate swimming season, blood lactate at near-maximal standard speed decreases by an average of between 27-35% without shaving. In the present study, the decrease in blood lactate as a result of shaving amounted to 23%. Thus, it can be said that within these subjects the effect of shaving was nearly as great as an entire season of training.

Another way to appreciate the magnitude of this effect is to examine the present data in terms of improvements in time over the distance used. It was stated that velocity on the all-out 200 yard swim was significantly faster after shaving but improvements in speed could have been a result of the subjects expecting to swim faster after shaving and thus exerting a greater effort. If this were the case in the present study, then we would expect such a "placebo effect" to cause an increase in blood lactate in proportion with the faster time. However, as shown in the results, blood lactate was not significantly higher after the all-out post-shave swim. Nevertheless, if we use the maximum blood lactate from the pre-shave trials and determine the post-shave time that would result in this lactate value, then average 200 time would be 2:15.0 ± 6.4 sec. This is significantly faster than the time which occurred pre-shave (2:21.6 ± 6.5 sec) at the same blood lactate concentration and agrees very closely with the average time which was actually achieved on the post-shave all-out trial (2:15.5 ± 6.2 sec). It should be obvious, therefore, that reducing body drag by whatever means available should perhaps occupy a greater portion of coaches efforts in preparing swimmers than it presently does.

A reduction in the physiological effort required to maintain a given swimming speed can be brought about by a decreasing body drag. Earlier research suggests that the primary components of body drag (active drag) are form drag, wave drag, skin resistance and eddy resistance. Of these components, the one that is probably most affected by shaving hair is skin resistance. The present data do not, however, allow us to be certain that shaving body hair reduces body drag enough to account for the amount of decrease we observed in blood lactate accumulation. It could be argued that shaving body hair improves one's efficiency by improving their ability to sense and thus eliminate non-propulsive and energy consuming movements. Further research employing direct determinations of body drag are therefore needed to identify the mechanism by which removal of body hair reduces the physiological cost maintaining any given swimming speed. It would also be useful to determine if the other strokes are affected as much by shaving.

Practical Applications

Not all swimming coaches agree that there is a physical justification for swimmers to shave their body hair before major competition. In part this may be due to the lack of objective evidence of the effect. The present data provide a beginning to our understanding of why shaving seems to offer such an advantage. Furthermore, since the effects of shaving appear to be due to more than just a psychological boost, shaving down for competition more often during a season can be justified. There is no reason to expect that repeated shaving would diminish the amount of biomechanical and physiological effects that can be derived. This must, however, be counterbalanced with the consideration of possible psychological benefits that might occur from "saving the shave" until the major competition.

These results may also have implications for the way in which we view the role played by body drag in determining a swimmer's performance capacity. Certainly many coaches already appreciate the need to incorporate strategies for decreasing body drag (i.e., streamlining, body position, etc.) into training programs. But there are many swimming programs that strive to achieve so much daily training yardage that there is little time or energy left for technique training. Some coaches may not realize the extent to which small changes in body drag might affect the physiological effort required to swim fast. The present data demonstrate that the potential return from reductions in body drag can be rather substantial. Thus, it may be wise for some coaches to spend more time working on drag reduction in place of some of the physiological training thereby contributing to greater improvements in performance and minimizing the risk of overtraining.

References

Muscle Glycogen Depletion During Swimming Interval Training

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Abstract

The intent of this investigation was to describe the effects of interval, front crawl swimming on muscle glycogen metabolism. The first phase of this research (Project A) examined the effects of interval training on the rate of glycogen use from the posterior deltoid muscle during repeated 100 (91.4 m) and 500 yd (457.2 m) bouts of front crawl swimming. The subjects swam a total distance of 6000 yd (5486 m) during each of these interval training sessions. A second study (Project B) examined the rate of glycogen resynthesis in the first eight hrs following a 3000 yd (2743 m) interval training session. During this eight-hr recovery period the subjects were fed a meal containing 112 g of carbohydrate. Significantly more muscle glycogen was used during the repeated 100 yd swims than during the 500 yd repetitions, demonstrating the effect of swimming intensity on the rate of muscle glycogen use. Histological examination of these muscle samples, however, revealed similar patterns of glycogen depletion from the type I and II fibers in both 100 and 500 yd interval sessions. The major finding of Project B was the relatively inadequate recovery of muscle glycogen during the eight-hr rest-feeding period that followed the 3000 yd training session (i.e. 6 x 500 yd; 1' rest). These data provide a better understanding of the impact of interval training on muscle glycogen reserves, and the risk of low muscle glycogen when swimmers train twice per day.

The energy requirements of intense muscular effort place severe demands on muscle glycogen reserves (6,9). Current training methods for competitive swimming employ, to a large extent, repeated bouts of intense exercise with relatively short intervals of rest (i.e., interval training). Much of this training is performed at swimming velocities that require more than 90% of the swimmer's VO2 max, placing heavy demands on muscle glycogen reserves (1,2,3). The rate of muscle glycogen use is dependent on the relative intensity (% VO2 max) and duration of exercise(9). Since swimmers often perform two such interval training sessions each day, expending more than 3000 kcal, muscle glycogen depletion and subsequent repletion, may become a determinant of exercise tolerance in these athletes. To date, however, there is no information to describe the rate of muscle glycogen use during interval swimming training, nor the rate of glycogen resynthesis between training sessions. Thus, the intent of this investigation was to examine the effect of interval training on muscle glycogen depletion.

Specific attention has been given to the rate of muscle glycogen use by selective muscle fiber types during repeated bouts (100 and 500 yd) of front crawl swimming. In addition, measurements have been made to describe the amount of muscle glycogen resynthesis that can occur between training sessions when the swimmers are fed a light carbohydrate meal and allowed to rest for 8 hrs.

Methods

This study was conducted in two parts. The first investigation (Project A) examined the effects of interval training on the rate of muscle glycogen use during repeated 100 (91.4 m) and 500 yd (457.2 m) bouts of front crawl swimming. The second phase of this research (Project B) examined the rate of glycogen resynthesis in the first eight hours following a 3000 yd (2743 m) interval training session.

Project A. Four male, collegiate swimmers gave their written consent to serve in this phase of the study after
being fully informed of the risks and stresses associated with these trials. Mean characteristics of these subjects are shown in Table I. All of the men had been training regularly for the preceding five months, swimming an average of 7000 yd (6400 m) per day. Front crawl was the specialty stroke for all of these swimmers.

On two separate days each swimmer performed an interval training workout consisting of either 60 repeated 100 yd (91.4 m) front crawl swims with 20 sec rest between repeats, or 12 repeated 500 yd (457.2 m) swims with one min rest between each swim. Thus, the total distance swum during each of these training sessions was 6000 yd (5486 m). The average velocities maintained by the swimmers were subjectively determined, though they were encouraged to maintain a hard, even pace throughout the interval set. As a result, the men averaged 64.4 sec per 100 yd (1.42 m/sec) during the repeated 100 yd intervals, and 69.0 sec per 100 yd (1.33 m/sec) during the 500 yd intervals. Based on recent studies by Beltz (1), it is estimated that these exercise intensities required the swimmers to use 100% VO₂ max during the 100 yd intervals and 93% VO₂ max during the 500 yd intervals. Venous blood lactate was determined from samples taken before, after 3000 yd, and after 6000 yd of swimming (5).

On the days of these studies, muscle biopsies were taken from the posterior deltoid of each swimmer before exercise, and after completing 3000 (2743 m) and 6000 yd (5486 m) of interval, front crawl swimming (3). Each specimen was divided into two parts. One portion of the sample (10 to 15 mg) was immediately frozen in liquid nitrogen, whereas the second piece was mounted in OCT and frozen in isopentane that had been cooled over liquid nitrogen. The first portion of the muscle was divided into three parts, weighed, and analyzed for glycogen content as previously described (7). Serial sections of the mounted specimen were stained for fiber composition (myosin ATP-ase, pH 4.3), and glycogen (Periodic Acid-Shiff's reaction, PAS) (8).

Microscopic examination of the ATP-ase and PAS stained sections was performed to estimate the glycogen content in the type I and II muscle fibers (5). The glycogen content of the fibers was rated as dark (highest), moderate, light, and negative (no glycogen). On the average, 456 (43) type I fibers and 256 (15) type II fibers were judged for glycogen content for each sample using this technique. Differences between mean values were tested for significance using a paired t-test, with the level of confidence set at 0.05.

**Project B.** In an attempt to determine the rate of muscle glycogen resynthesis after interval training, six collegiate, male swimmers were biopsied (posterior deltoid) before, immediately after, and 8-hr after a 3000 yd (2743 m) interval training session. These muscle samples were analyzed in the same manner as described in Project A. The interval workout involved six, 500 yd (457.2 m) front crawl swims with one min rest between each. The swimming pace during these repeated efforts averaged 1.26 m/sec (69.8 sec/100 yd), an exercise intensity estimated to require approximately 85% of the swimmer's VO₂ max (1). Heart rates were obtained at the end of each interval swim by palpating the swimmer's carotid artery. Ninety min after the training session the men were fed a meal (848 kcal) containing 112 g of carbohydrate, 60 g of protein, and 18 g of fat. The swimmers rested during the 8-hr period that followed the training session. Differences between the means for muscle glycogen were treated for significance with a paired t-test (P < 0.05).

**Results**

After 3000 yd of swimming, similar (P > .05) blood lactate values were observed during the repeated 100 yd (mean = 3.6 mmol/liter) and 500 yd (mean = 3.2 mmol/liter) swims. It is interesting to note that mean lactate values declined during the final 3000 yds of the 100 and 500 yd interval swims (means = 2.0 and 1.8 mmol/liter, respectively). Muscle glycogen used during the first 3000 yd of swimming was significantly greater (P < .05) during the repeated 100 yd intervals ( = 89 mmol/kg w.w.) than after the 500 yd repeated swims ( = 69.5 mmol/kg w.w.). As shown in Figure 1, at the completion of the 60, 100 yd swims muscle glycogen was 16.5 mmol/kg w.w., significantly less than that observed after the final 500 yd intervals (48.3 mmol/kg w.w.).

Visual inspection of the muscle sections that were stained for glycogen (i.e., PAS) revealed a similar pattern of depletion for the type I and II fibers. This pattern of depletion was similar for the samples taken during the 100 and 500 yd interval trials. As shown in Figure 2, more than 80% of the type I and II fibers were darkly stained with glycogen at the start of the exercise.

| Table 1. Mean (±SE) characteristics of the subjects in projects A and B. |
|-----------------|-----|------|-----|-----|-----|
| Project | N  | Age (yr) | Ht. (cm) | Wt. (kg) | %Fat | Type I |
| "A" | 4  | 21.5 (1.2) | 184 (2) | 77.2 (4.5) | 12.4 (1.2) | 69.6 (1.9) |
| "B" | 6  | 19.0 (0.6) | 179 (2) | 76.3 (1.6) | 12.2 (0.4) | 64.8 (4.2) |

%Fat determined from skinfold measurements (10)
%Type I denotes the percentage of type I fibers (slow twitch fibers) in the posterior deltoid m. of the swimmers.
However, after 3000 yd of interval swimming, the dark glycogen stain was found in less than 20% of the fibers (type I and II), whereas approximately 10% of the fibers were without any glycogen stain. At the completion of the 6000 yd interval sessions, more than 90% of the muscle fibers had no glycogen stain. The microphotographs shown in Figure 3 illustrate that both fiber types utilize glycogen at about the same rate during the 100 yd repetitions. A similar pattern of muscle glycogen use was seen during the 500 yd intervals performed in Project B. That is to say, the interval swimming performed in Projects A and B showed similar rates and degrees of muscle glycogen use from the type I and II fibers.

Figure 4 illustrates the rate of muscle glycogen use and resynthesis during Project B. As a consequence of the six, 500 yd front crawl swims, muscle glycogen declined by 70.1 mmol/kg w.w.. Eight hrs of rest and the intake of 112 g of carbohydrate, on the other hand, resulted in a 52% (+36.3 mmol/kg w.w.) recovery of muscle glycogen. Mean muscle glycogen contents before, and after the exercise and recovery were all significantly different (P < .05) from each other.

Discussion
One of the major findings of this research was the dramatic depletion of the arm muscle glycogen during a single training session of 6000 yd of interval training.
The histological examination of muscle sections following the training sessions revealed that nearly all of the muscle fibers were empty of glycogen. In light of the muscle's reliance on glycogen for energy, it is surprising that the swimmers were able to maintain a steady swimming pace during the final 100 and 500 yd repetitions. In any event, these data clearly demonstrate the exhaustive nature of such interval training, and the greater rate of glycogen use during 100 yd interval swimming than during a similar volume of work performed in repeated 500 yd bouts. This difference in the rate of muscle glycogen use appears to be related to the relative intensity of swimming, since the men were able to perform each of the 100 yd swims approximately 7% faster than during the 500 yd repetitions.

Measurements of muscle glycogen use from selected muscle fibers have been used to estimate the recruitment pattern used during exercise (6). Gollnick et al. (6) have shown that type I fibers provide most of the force development during low-intensity, aerobic activities. As the muscle tension requirement increases at faster swimming speeds, the type II fibers are added to the pool of contracting fibers to increase the force of contraction. At the swimming speeds employed in the present study, it appears that the type I and II fibers in the posterior deltoid muscle contribute equally to the force required in these 100 and 500 yd interval swims.

The utilization of both fiber types during training is important to the specific adaptations for competitive swimming. Most competitive swimming events are performed in less than 2.5 min, thereby demanding the recruitment of a maximal number of type I and II fibers. Consequently, training these fibers for competitive performance necessitates that they be utilized during training. Since slow, low-intensity training tends to recruit only type I fibers, such training would not promote adaptations in the type II fibers. Thus, interval training at the intensities used in this study would be expected to stress the muscle fibers and energy systems employed during competition.

A second, major finding of this research was the relatively inadequate recovery of muscle glycogen during the rest-feeding period that followed the 3000 yd training session (i.e., 6 x 500 yd; 1' rest). Swimmers often train twice each day, covering more than 5000 yd in each training session. The data presented in Project B suggests that these swimmers would have become glycogen depleted if they attempted such a training regimen. Recent studies have shown that muscle glycogen depletion and the inability to resynthesize muscle glycogen between training sessions may be the primary cause for overtraining observed in some athletes (4). Although it is difficult to use the findings from these men to predict the impact of such training on other swimmers, it is apparent that all swimmers should consume a carbohydrate-rich meal during the rest period between training sessions.

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Abstract

In keeping with the original intent of the JSR, to act as "researcher-to-coach" publication and to "educate coaches while informing them" the following bibliography has been compiled to serve the swimming community. Not all swimming related material is found within this listing. An attempt was made to include only those references judged by the authors to be information or research oriented and valuable to the swimming coach. It is hoped that this bibliography will be helpful by providing a quick and easy guide to information. Suggestions which may improve the usefulness of this index to the swimming community are welcome.

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