Energy Demands of Interval Training for Competitive Swimming

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Energy Demands of Interval Training for Competitive Swimming

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Muncie, Indiana 47306

Abstract

The intent of this research was to describe the energy expenditure of front crawl swimming during interval training. Specifically, attempts were made to determine the influence of the rest interval and the distance of the repeated exercise bouts on the subjects' swimming pace. Preliminary studies were conducted to determine the swimmer's maximal oxygen uptake and the relationship between swimming velocity and oxygen uptake during front crawl swimming. This information was used to estimate the energy expenditure during interval sets of 25, 50, 100, 200, and 400 yd (i.e., 22.9, 45.7, 91.4, 182.9, and 365.8 m, respectively). Rest intervals of 10, 30, 60, and 180 sec were used during the selected interval sets. The results of this study demonstrate that during interval training the swimmers voluntarily select a pace and %VO2 max that will enable them to tolerate the distance, number of repetitions, and rest interval between each exercise bout. These data support the theory that short, maximal sprints (e.g. 25 yd with 30 or 60 sec. rest) place the greatest demands on the ATP-CP system for energy production, while stimulating the specific adaptations associated with strength and power. Training of the glycolytic system, on the other hand, appears to be best achieved by performing interval sets of 50 and 100 yd, with the longest rest intervals (i.e., 60 to 180 sec.). The aerobic system appears to provide most of the energy for interval sets of greatest distance (≥ 200 yd) and shortest rest intervals (≤ 30 sec.). This study has identified the energy demands of intermittent front crawl swimming, and has provided a basis for future studies concerning the adaptations to interval training.

Introduction

The adaptations associated with physical training have been shown to be specific to the mode of exercise, intensity and duration of the activity employed during training (1,3,11). Exclusive use of aerobic exercise during training, for example, tends to enhance the oxygen transport system and increase the respiratory capacity of the muscles used during training (3). Such activity, on the other hand, does little to enhance the muscle's capacity for glycolytic energy production, buffering, or strength; factors which improve only with sprint training (3,9). The use of intermittent exercise during training (i.e., interval training) has been shown to effectively enhance the qualities important for both sprint and endurance performance (11). Although this method of training is widely used by competitive swimmers, there have been few attempts to quantify the energy demands of varied forms of interval training, or to define the influence of the rest interval between repeated bouts on swimming speed. Such information is important for the effective use of this mode of training, and will enable the coach to design a training program that will produce the specific adaptations desired for optimal performance.

Consequently, the intent of this study was to examine the energy demands of selected forms of interval swimming training. Specifically, we wished to determine the influence of the rest interval between the intermittent exercise bouts on the swimmer's velocity during repeated swims of 25, 50, 100, 200, and 400 yd (i.e., 22.9, 45.7, 91.5, 182.9, 365.8 m, respectively). No attempt was made to control the swimmer's velocity during the exercise. Since the subjects used in this study were all highly motivated, experienced collegiate swimmers, it was anticipated that they would choose to swim the prescribed
interval session at a velocity that approached their limits of tolerance. As a result, the data presented in this study describe the subjectively determined efforts of a select group of highly trained collegiate male swimmers, which may not be totally applicable to other groups of swimmers (e.g. females, younger, and/or older swimmers).

Methods and Procedures
Nine male collegiate swimmers were used as subjects after giving their written consent to participate in this study. All of the men had been training for at least nine weeks prior to this investigation. Table 1 presents the characteristics and best swimming performances of these subjects. In the first phase of this study, measurements were made to determine the swimmer's energy expenditure (VO₂) and heart rate responses during front crawl swimming at velocities ranging from 1.0 to .15 m/sec. In these trials, each swimmer performed 8 to 12, 400 yd (365.8 m) submaximal and maximal front crawl swims. Oxygen consumption during each swim was estimated using an immediate post-exercise (40 sec) collection of expired air (2, 8). Previous experiments from this laboratory have demonstrated that this method provides both valid and reliable measurements of oxygen consumption during exercise (2). The concentrations of CO₂ and O₂ were determined electronically, using a Beckman LB-2, (CO₂), and Applied Electrochemistry S-3A, (O₂) analyzers. Gas volumes were determined using a Parkinson-Cowen dry gas meter. Each of the submaximal swims was paced by a computer based light system positioned along the bottom of the pool (Pacer Products). Heart rates were determined using a modified Quantum XL heart rate monitor adapted for use in the water. Heart rate was recorded every 5 seconds and averaged for each submaximal and maximal swim. The relationships between swimming velocity and VO₂ for these subjects are shown in Figure 1. Individual linear regressions for swimming velocity and VO₂ were used to estimate each swimmer's energy expenditure during interval training.

Table 1
Mean (±SE) characteristics and best performance data (sec/400 and 1000 yd front crawl) for the subjects in this study.

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Ht (cm)</th>
<th>Wt (kg)</th>
<th>%*</th>
<th>VO₂ max (L/min)</th>
<th>H.R. max (bts/min)</th>
<th>Performance (sec) 400 yd</th>
<th>Performance (sec) 1000 yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.4</td>
<td>183.4</td>
<td>78.7</td>
<td>9.7</td>
<td>4.23</td>
<td>180</td>
<td>249.3</td>
<td>653.7</td>
</tr>
<tr>
<td>±0.7</td>
<td>±3.2</td>
<td>±0.8</td>
<td>±1.1</td>
<td>±0.14</td>
<td>±6</td>
<td>±12.0</td>
<td>±23.5</td>
</tr>
</tbody>
</table>
* Determined from skinfold measurements (13)

The second phase of this investigation involved the recording of swimming times during interval training. Fourteen different sets of interval swimming were completed by each swimmer. A list of the interval sets performed in this phase of the study is presented in Table 2. In addition, a continuous 1000 yd. swim was performed by the subjects. All of the swims were performed during practice time after a standard warm-up of 400 yd (365.8 m) swimming and 400 yd kicking.

Table 2
The interval sets used in phase 2 of this study are designated by the number of repeated front crawl swims, distance of each swim, and rest interval between repetitions. Linear regression equations for swimming velocity and oxygen uptake (VO₂) were used to estimate the VO₂ required during each of the interval sets. In addition to the interval sets, the swimmers performed a single 1000 yd (914.4 m) front crawl swim for time (*).

<table>
<thead>
<tr>
<th>Number of Reps of Swim (yd)</th>
<th>Distance (yd)</th>
<th>Test (sec.)</th>
<th>Velocity (m/sec)</th>
<th>VO₂ (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>25</td>
<td>10</td>
<td>1.56 (±.04)</td>
<td>5.05 (±.42)</td>
</tr>
<tr>
<td>40</td>
<td>25</td>
<td>30</td>
<td>1.94 (±.03)</td>
<td>6.94 (±.21)</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>10</td>
<td>1.46 (±.04)</td>
<td>4.49 (±.12)</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>60</td>
<td>1.65 (±.02)</td>
<td>5.46 (±.05)</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
<td>180</td>
<td>1.71 (±.03)</td>
<td>5.77 (±.15)</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>10</td>
<td>1.41 (±.04)</td>
<td>4.34 (±.19)</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>60</td>
<td>1.55 (±.03)</td>
<td>4.95 (±.10)</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>180</td>
<td>1.61 (±.04)</td>
<td>5.26 (±.33)</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>10</td>
<td>1.31 (±.02)</td>
<td>3.73 (±.08)</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>60</td>
<td>1.42 (±.03)</td>
<td>4.29 (±.06)</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>180</td>
<td>1.48 (±.04)</td>
<td>4.60 (±.21)</td>
</tr>
<tr>
<td>1*</td>
<td>1000</td>
<td>--</td>
<td>1.39 (±.06)</td>
<td>4.14 (±.19)</td>
</tr>
</tbody>
</table>

The swimmers completed each of the interval sets without being informed of the time for each swim. These sets were completed with only the quantitative information regarding the number of repeated swims, and the duration of the rest interval. The purpose for limiting the feedback to the swimmers was to examine the influence of the interval distance, rest interval, and number of repetitions on the pace selected by the swimmers. We hypothesized that an experienced swimmer would perform selected interval bouts at a self-determined intensity (%VO₂ max) based on the distance of the swim and the rest interval. In an attempt to minimize any motivational...
influence of the timers on the swimmer’s pace during the intervals the investigators conducted all observations and timing out of view of the swimmers. The average speed for each set was calculated and expressed in m/s. Individual regression equations were used to predict the swimmer’s oxygen cost for that set. It was assumed that this relationship remained linear above 100% VO₂ max, which may not be true. Consequently, our calculations of energy expenditure during the interval sets may have underestimated the actual energy cost of swimming at velocities that required more than 100% VO₂. Nevertheless, the exercise intensity for all interval swims was expressed as a percent of each swimmer’s maximal oxygen uptake (%VO₂ max), estimated from the 400 yd swims.

In the third phase of this study, each of the nine swimmers was randomly selected to duplicate four of the interval sets studied in the second phase of the investigation. During these trials, blood samples were collected after the warm-up and at 1, 3, 5, and 7 minutes following the completion of the interval set. The velocity of these swims was controlled by the use of the pacing lights along the bottom of the pool. The standardized warm-up before these trials involved a 400 yd swim and a 400 yd flutter kick. Heart rate was recorded throughout the interval set as described earlier.

**Analysis**

Approximately 4 ml of venous blood was taken from a forearm vein for lactate and pH determinations. An aliquot of 0.5 ml was deproteinized in 1 ml of perchloric acid. The remaining 3 ml of whole blood was kept anaerobic in an ice bath for subsequent determination of pH. Lactate concentration was determined spectrophotometrically (12), whereas pH was measured with a Radiometer blood gas analyzer that had previously been calibrated with pH buffers (7.38 ± .001 and 6.84 ± .003).

**Results**

Since the findings of this study are based on the relationship between the swimmer’s VO₂ and swimming velocity, it is worthy of note that the individual correlations for VO₂ and velocity ranged from 0.90 to 0.99 (Figure 1). As expected, however, there was considerable variation in the slope (range: 3.86 to 7.7) and intercepts (range: −0.14 to −5.57) of the swimmers’ regressions. It is assumed that these individual variations reflect differences in swimming economy and body drag.

Table 2 presents the mean (± SE) values for the swimmers’ velocities and calculated VO₂ during each of the interval sets, and during the continuous 1000 yd (914.4 m) front crawl swim. As anticipated, the swimmers were able to maintain the highest velocities during the interval sets that had the shortest distance (i.e. 25 yd) and the greatest rest (i.e., 180 sec.). In most cases, the estimated VO₂ for the swims was substantially higher than the mean VO₂ max for the subjects, suggesting that a large part of the energy needed for these repeated swims was derived from anaerobic energy sources. Only the continuous 1000 yd and 200 yd swims with 10 sec rest were estimated to use less than 100% of the subjects’ VO₂.

Figure 2 demonstrates the effect of swimming distance on the relationship between the rest interval and our estimates of %VO₂ max. As shown, the shortest rest interval (i.e., 10 sec) produced the lowest fractional utilization of the aerobic capacity, whereas rest intervals of one minute or longer enabled the swimmers to maintain the highest %VO₂ max at each swimming distance. It is interesting to note, however, that the swimmers’ velocities increased little (~6%) when the rest intervals were greater than one minute. This is not to say there was no metabolic impact of this increase in swimming speed.

![Figure 2](image-url)

**Figure 2.** The influence of swimming distance (25 to 200 yd) and rest interval on the percentage of the swimmers’ maximal oxygen uptake (%VO₂) during various interval sets. Values noted with an asterisk were obtained for six rather than nine subjects.

To the contrary, measurements of blood lactate and pH demonstrated that this small increase in swimming speed placed significantly greater demands on glycolysis. During the 100 yd (91.5 m) interval set, for example, blood lactate increased 6.3 mmol/l when the rest interval was increased from one to three minutes (Table 3). The lowest blood lactates and highest pH values were observed after the sets having the shortest rest interval (i.e., 10 sec). Similarly, the highest heart rates (peak heart rates) were observed during the interval sets having the longest rest periods (Table 3).

Consequently, the data for %VO₂ max, lactate, blood pH, and heart rates all indicate that longer rest intervals impose greater demands on the swimmers’ anaerobic process of energy production (i.e., ATP-CP and glycolysis). Whereas, the shortest rest intervals were more aerobic, resulting in a lower %VO₂ max, lactate, heart rate, and higher blood pH.
Table 3
Mean (± SE) values for venous blood lactate, pH, and bicarbonate (HCO₃⁻) after selected interval sets. Resting blood lactate, pH, and HCO₃⁻ averaged 1.6 mmol/l, 7.363, and 25.6 mmol/l, respectively. Peak heart rates (Peak H.R.) represent the average for the highest heart rates recorded during each of the repeated bouts.

<table>
<thead>
<tr>
<th>Distance (Repeats)</th>
<th>Rest Interval</th>
<th>Lactate (mmol/l)</th>
<th>pH</th>
<th>HCO₃⁻ (mmol/l)</th>
<th>Peak H.R. (bts/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 yd (22.9 m)</td>
<td>10 sec</td>
<td>2.9 (1.0)</td>
<td>7.272</td>
<td>25.2 (3.1)</td>
<td>157 (3)</td>
</tr>
<tr>
<td></td>
<td>10 sec</td>
<td>7.2 (0.9)</td>
<td>7.226</td>
<td>19.8 (2.3)</td>
<td>171 (5)</td>
</tr>
<tr>
<td></td>
<td>60 sec</td>
<td>9.0 (0.5)</td>
<td>7.233</td>
<td>21.3 (4.0)</td>
<td>173 (3)</td>
</tr>
<tr>
<td>50 yd (20)</td>
<td>10 sec</td>
<td>8.0 (1.7)</td>
<td>7.174</td>
<td>19.8 (1.0)</td>
<td>175 (4)</td>
</tr>
<tr>
<td></td>
<td>60 sec</td>
<td>10.0 (2.8)</td>
<td>7.165</td>
<td>18.5 (2.8)</td>
<td>176 (5)</td>
</tr>
<tr>
<td></td>
<td>180 sec</td>
<td>16.4 (1.8)</td>
<td>7.050</td>
<td>14.6 (2.8)</td>
<td>180 (3)</td>
</tr>
<tr>
<td>100 yd (10)</td>
<td>10 sec</td>
<td>3.6 (1.4)</td>
<td>7.236</td>
<td>25.0 (1.8)</td>
<td>170 (3)</td>
</tr>
<tr>
<td></td>
<td>60 sec</td>
<td>8.7 (2.6)</td>
<td>7.164</td>
<td>17.0 (4.7)</td>
<td>178 (3)</td>
</tr>
<tr>
<td></td>
<td>180 sec</td>
<td>13.3 (3.2)</td>
<td>6.920</td>
<td>16.4 (4.8)</td>
<td>180 (3)</td>
</tr>
</tbody>
</table>

Discussion and Practical Applications
This study was designed to estimate the metabolic demands of varied interval training sessions. It is recognized that these data have several limitations in that these findings may only represent the subject sample in this study (i.e., male, collegiate swimmers), and may only be applicable to front crawl swimming. We have more recently, however, examined other groups of swimmers (i.e., males and females; 25 to 52 yr) and different strokes (i.e., backstroke and breaststroke), and have obtained essentially the same relationships between the interval rest periods and %VO₂ max as have been observed in this study (unpublished). In addition, these older swimmers experienced similar changes in blood acid-base balance as a consequence of the various interval sets. We are, therefore, inclined to feel that these findings can be applied to other swimmers, though we have some reservations regarding their application to younger swimmers (e.g., pre-adolescent boys and girls).

It is also recognized that these measurements do not encompass all of the forms of interval training currently employed by swimmers. Nevertheless, the interval set selected for this study cover the range of sets most frequently practiced by swimmers, and can be used to estimate the energy demands of other interval training sessions.

The major finding of this study was the relationship between rest interval and %VO₂ max. These data suggest that swimmers voluntarily select a swimming speed that will accommodate the distance, number of repetitions, and rest for various interval sets. Measurements of blood lactate and pH indicate that nearly all of these interval training sessions stressed the glycolytic energy system (4, 5, 6, 7). These data, however, must be interpreted with some precautions since measurements of lactate and hydrogen ions (pH) are not directly applicable to the metabolic processes within the muscle fibers. Their rate of production within and diffusion from the exercising muscles cannot be judged by their accumulation in blood, since these constituents will be influenced by the intensity, duration, and rest interval for each set. In addition, acid-base balance is rapidly adjusted between repeated swims via the respiratory removal of carbon dioxide. These points are illustrated by the relatively low blood lactate (2.9 mmol/l) and high pH (7.272) observed after the swimmers performed 40 repetitions of 25 yd at nearly 120% of VO₂ max. Twenty repetitions of 45.7 m with the same rest interval (10 sec), on the other hand, resulted in a lactate accumulation of 7.2 mmol/l, with a blood pH (7.226) that was nearly identical to that observed after the 25 yd repetitions.

Another point that must not be overlooked, is the contributions of the ATP-CP system for energy production during maximal sprint swimming (1, 7, 14). This lactate system for energy production may explain why the swimmers are able to perform repeated 25 yd swims (60 sec rest) at an estimated intensity of nearly 200% VO₂ max with little accumulation of blood lactate (<6.3 mmol/l) or decline in pH.

The findings of this study provide the coach and swimmer with a better understanding of the energy demands of interval training. From a practical point of view, these data make it clear that experienced swimmers voluntarily select swimming speeds and a %VO₂ max that they can tolerate for each prescribed interval training session. Although the subjectively selected intensity was influenced by the number of repetitions, rest interval, and distance of each set, it is our impression that the designated rest interval has the greatest impact on the swimmer's chosen swimming velocity. We cannot overlook the important influence of prior training experience on the swimmer's conscious selection of swimming speed for any given interval set. This may explain why there was a relatively small individual variation in the %VO₂ max used by each swimmer during each of the interval training sessions.

As noted earlier, the adaptations to chronic exercise are specific to the mode, intensity, and duration of the
exercise employed during training (3,9,11). Consequently, various forms of interval training provide specific demands which can stimulate adaptations to the three major systems of energy production (i.e., ATP-CP, glycolysis, and oxidation). It appears that interval sets which employ short swims (e.g., 25 yd) and long rest periods (e.g., 30-60 sec), may provide selective stimulus for adaptations within the ATP-CP system (3,10). At the other extreme, longer swims (e.g., 100-200 yd) with a short rest interval (e.g., 10 sec) place the greatest demands on oxygen transport and oxidative energy production, thereby stimulating the adaptations for aerobic metabolism (11). The glycolytic system, on the other hand, appears to be most severely stressed by interval sets that incorporate distances of 50 to 200 yd with relatively long rest intervals. Unfortunately, little is known regarding the actual impact of different interval training regimens on the adaptations to each of these energy systems. Until such information is made available, it is logical to assume that interval training offers a mode of exercise that will stimulate the specific adaptations needed for competitive swimming.

References

Blood Lactate Concentrations of Swimming, Pulling, and Kicking

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Much attention has been given to monitoring blood lactic acid levels resulting from various intensity swims. However, very limited information has been published regarding the blood lactate concentration responses to various intensities of the component parts of swimming: pulling and kicking. The purpose of the present study was to determine the blood lactate response of swimmers to various intensities of swimming, pulling, and kicking. Eleven male and 11 female members of a major university team were studied at three intensities each for swimming, pulling alone and kicking alone. Subjects, asked to swim, pull, and kick at 60% and 80% of maximal effort, instead performed at approximately 84% and 92% of effort, respectively. Significant differences were observed for both condition (swim, pull, kick) and for intensity of effort. Swimming at 100% effort produced significantly higher (p<.05) lactate levels than any other condition. Kicking at 100% effort produced significantly higher lactate levels than all submaximal swimming or kicking and all intensities of pulling.

Although lactate levels varied by condition and intensity, at a given intensity, values were of similar magnitudes for pulling and kicking as for swimming. Coaches should consider the substantial blood lactate accumulations resulting from pulling and kicking in planning their training programs. Individual swimmer's kick technique and lactate production levels should be considered in determining optimal training and style (i.e., two beat versus six beat).

Introduction

Lactic acid monitoring has become a popular technique among swim coaches over the last few years (Madsen, 1983; Maglischo, Maglischo, & Bishop, 1982; Maglischo, Maglischo, Smith, Bishop, & Hovland, 1984; Sharp, Vitelli, Costill, & Thomas, 1984; Trup, 1986). Although practical considerations have precluded actual scientific verification of the efficacy of lactate monitoring as a training technique, lactate concentrations can provide coaches with an objective estimate of effort.

Our interest was in determining the concentration of blood lactic acid produced by the component activities of pulling and kicking in comparison to swimming at different intensities. Such information should be useful in helping individual swimmers achieve their best performance and also aid coaches and swimmers in making optimum use of training time and effort.

Optimum training methods include maximizing the effective use of aerobic and anaerobic sets which should also include kicking and pulling. Coaches must be aware of the physiological response to intense kicking efforts, intense pulling efforts, and high intensity swims. For optimal performance, swimming, pulling, and kicking must be incorporated into the workout with careful planning. Similarly, lower intensities must also be optimally employed for optimal results. The purpose of the present study was to determine the response of blood lactate concentrations to varied intensities of swimming, pulling, and kicking.

Methods

Subjects for this study were 22 varsity swimmers (11
male, 11 female) who were members of the NCAA Division I university team. All but one subject qualified for the U.S. Senior National Championships. All subjects were volunteers who gave informed consent in accordance with guidelines of the American College of Sports Medicine. Subjects had undergone 14 weeks of hard training prior to testing and had tapered and engaged in a major competition immediately prior to testing. Swimmers engaged in light workouts during the test period but did not participate in any dryland or strength training. Subject physical characteristics including body composition estimated from three skinfolds (Pollock, Schmidt, & Jackson, 1980), are displayed in Table 1.

Table 1
Mean (± s.d.) of physical characteristics of subjects

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>19.1</td>
<td>173.6</td>
<td>64.5</td>
<td>18.8</td>
</tr>
<tr>
<td>(n=11)</td>
<td>(1.4)</td>
<td>(5.8)</td>
<td>(7.6)</td>
<td>(4.3)</td>
</tr>
<tr>
<td>Men</td>
<td>19.9</td>
<td>186.6</td>
<td>81.2</td>
<td>7.6</td>
</tr>
<tr>
<td>(n=11)</td>
<td>(1.7)</td>
<td>(5.8)</td>
<td>(3.6)</td>
<td>(2.7)</td>
</tr>
</tbody>
</table>

In groups of four, swimmers were requested to either swim, pull, or kick at 60 and 100% of maximal efforts. The order of swimming, pulling, and kicking was randomly assigned for each group, but each condition was always swum in order from lowest to highest intensity. Fifteen minutes of rest were allowed between each test. Prior to any testing, swimmers swam a brief standardized warm-up and initial pretest lactate levels were measured. The initial pretest lactate, the low-to-high intensity test order, and the rest periods were all utilized to minimize the influence of previous warm-up or testing on subsequent testing. Only one condition (swim, pull, or kick) was tested any given day.

Subjects, who had on numerous previous occasions been subjected to similar pacing and blood sampling techniques in practice, were asked to swim or pull 200 meters of freestyle or kick 150 meters of freestyle at 60, 80, and 100% of effort. Pull buoys were used for pulling, and rubber bands were fastened around swimmers' ankles to prevent kicking. Swimmers were allowed to breathe at will. Experienced swim coaches recorded times for each trial. Shorter distances were employed for kicking trials in order to result in similar time durations for kicking as for swimming and pulling.

Between the first and second minutes following each submaximal exercise effort, blood was drawn from a warmed finger tip. Because of uncertainty as to when peak lactate concentrations occur following maximal exercise, blood was drawn 3, 5, 7, and 9 minutes after the 100% effort trial. Blood was collected with heparinized capillary tubes and was then drawn from capillary tubes with a 25 microliter syringe. The blood was then mixed with 50 microliters of a solution of 1.2 milliliters of Triton X-100 which had been added as a lysing agent to 450 milliliters of Yellow Springs Instrument (YSI) lactate buffer solution. For the 100% effort, the peak observed lactate was recorded for each subject.

Blood samples were then tested for lactate concentration with a YSI model 23L lactate analyzer. The lactate analyzer was initially calibrated with 2.5 millimolar and 5.0 millimolar standards prior to testing and after every five samples. Results were analyzed with analysis of variance with repeated measures. Post hoc analysis was performed with Tukey's HSD procedure. A p < .05 significance level was utilized for all testing.

Findings
Although the swimmers were instructed to swim at 60 and 80% of maximal effort for submaximal swimming, pulling, and kicking, actual efforts were much higher, averaging 84% and 92% of maximum, respectively. Actual mean percentages (± s.d.) of effort and velocities for each test are displayed in Table 2. Mean lactate concentrations (± s.d.) for swimming, pulling, and kicking at each intensity are displayed in Table 3.

Table 2
Mean (± s.d.) of actual percentage of effort and velocity for swimming, pulling, and kicking

<table>
<thead>
<tr>
<th>Requested</th>
<th>Actual</th>
<th>Velocity</th>
<th>Actual</th>
<th>Actual</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(%)</td>
<td>(%)</td>
<td>(m/sec)</td>
<td>(m/sec)</td>
<td>(m/sec)</td>
<td>(m/sec)</td>
</tr>
<tr>
<td>100</td>
<td>100(−)</td>
<td>1.49(10)</td>
<td>100(−)</td>
<td>1.41(12)</td>
<td>100(−) 1.03(09)</td>
</tr>
<tr>
<td>80</td>
<td>92.6(2.5)</td>
<td>1.38(68)</td>
<td>93.3(11)</td>
<td>1.21(10)</td>
<td>90(6.9) 92(10)</td>
</tr>
<tr>
<td>60</td>
<td>85.9(3.2)</td>
<td>1.28(88)</td>
<td>85.4(5.3)</td>
<td>1.23(10)</td>
<td>80.0(6.7) 81(10)</td>
</tr>
</tbody>
</table>

Table 3
Mean (± s.d.) of lactate concentration for swimming, pulling, and kicking by intensity

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Swim (mmol)</th>
<th>Pull (mmol)</th>
<th>Kick (mmol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7.81 (1.19)</td>
<td>5.41 (2.19)</td>
<td>6.48 (1.91)</td>
</tr>
<tr>
<td>92</td>
<td>3.38 (1.13)</td>
<td>2.92 (1.25)</td>
<td>3.11 (1.45)</td>
</tr>
<tr>
<td>84</td>
<td>1.77 (0.65)</td>
<td>1.73 (0.72)</td>
<td>1.76 (0.96)</td>
</tr>
</tbody>
</table>

A statistically significant interaction between the conditions of swim, pull, and kick, and intensity was found. Post hoc analysis revealed that the maximal swim lactate level was significantly higher than both the submaximal swims and all conditions of pull and kick. Swimming at 92% effort produced a mean lactate level significantly higher than swimming, pulling, and kicking at 84%. Lactate levels for maximal kick were significantly higher than submaximal kick and swim, and also significantly higher
than all lactate levels for pulling. Kicking at 92% produced significantly more lactate than did swimming and pulling at the lowest level (84%). Pulling at 100% produced significantly higher lactate levels than any submaximal swimming, pulling, or kicking effort.

Discussion

The purpose of this study was to determine the blood lactate concentrations produced by component activities of pulling and kicking and to compare these to lactate concentrations produced in swimming. This was done at three different intensities. Surprisingly, for the two submaximal tests, our subjects swam, pulled, and kicked at speeds much higher than requested. This was probably due to a combination of factors. Cazorla, Dufort, Cervetti, and Montpetit (1982) found that skilled swimmers had difficulty maintaining a swim pace requiring very low (30-50) percentages of maximal aerobic capacity. These authors suggested that such low speeds compromise correct technique, body position, and efficiency and are thus uncomfortable for well-trained swimmers.

The similarity of percent effort across swimming, pulling, and kicking was also noteworthy. Apparently the factors that affected the subjects' sense of pace in swimming also affected pulling and kicking, although kicking had a somewhat greater variation.

In our study, the athletes' training routine had been interrupted by taper, competition, light workouts, and absence of dryland and strength training. We had deemed these conditions as desirable, in that we did not want the subjects to be hampered by fatigue. The particular training circumstances of our subjects may have affected their perception of intensity. Although these latter disruptions would not be present during most of the training season, coaches and swimmers should be aware that under some conditions, swimmers may need close monitoring and observation to achieve a particular submaximal swim, pull, or kick rate.

The lactate concentrations for maximal swimming found in the present study are similar to the mean levels reported for men (7.35 mmol) and women (8.27 mmol) who swim a 200 meter maximal swim at the U.S. Sports Medicine Committee's Athlete Testing Program (Trup et al., 1984). Undoubtedly, in both studies, the total mean maximal lactate concentration observed was influenced by the mixture of sprint, middle distance, and long distance swimmers. It is interesting to note that the peak lactate values during a competitive swim meet may rise as high as 16 to 22 mmol (Madsen, 1983). Coaches should be aware that optimal conditions, adrenalin, and psychological motivation play an important role in observed blood lactate concentrations.

Maximal swimming produced significantly higher lactate levels than maximal pulling or kicking. The same result was consistently observed for both the 92% and 84% conditions. The lactate concentration resulting from swimming at a given percent of maximum was not the sum of that produced by each component at that percentage.

Kinderman and Keul (1977) conducted a study somewhat similar to the present study. Their swim, pull, and kick treatment was $8 \times 50$ meters with a 3 minute rest between each 50 meters. An intra-individual comparison showed significantly lower lactate levels for pulling than for kicking. Similar lactate levels were observed for swimming and kicking.

Conclusions

The primary motivation for conducting this study was to produce information useful to coaches regarding the lactate levels resulting from the components of swimming. The findings regarding kicking are particularly noteworthy. The high lactate levels produced in kicking has important implications. Lactate production for 100% effort kicking and swimming were of the same magnitude, whereas the speeds produced were 1.02 m/sec and 1.49 m/sec, respectively. Since kicking contributes little to swim speed, over-kicking early in a race could contribute excessively and unnecessarily to lactate production.

The fairly high lactate production of the arms and shoulders alone when pulling, particularly relative to their small muscle mass in comparison to the whole body, also should be noted. Since the arms and shoulders play such a vital role in swimming, monitoring the lactate profile of pulling alone, and not confounded by lactate produced from kicking, might be of value to coaches and athletes.

The maximal efforts of swimming and pulling produce similar velocities, 1.49 m/sec and 1.41 m/sec respectively, although the lactate production of pulling (5.41 mmol) was significantly less than swimming (7.81 mmol). It should be kept in mind that our subjects used pull buoys which may produce a body position in the water which might result in less drag than occurs with kicking. It seems that if a swimmer's body position is adequate using a minimal kick and a strong pull, minimizing kick should reduce lactate production at a given velocity. However, if the use of the legs is increased in the latter stages of the race, the resulting higher accumulations will have relatively little influence on performance, yet some gains in velocity due to increased kick may result.

It should be remembered that our data and conclusions represent no single individual, but are group data. As Stegman, Kinderman, and Schnabel (1981) point out, each swimmer must be tested and trained as an individual. It is suggested that further research comparing the differences of lactate values of swim, pull, and kick of sprinters versus distance swimmers would be of interest. Coaches and swimmers might consider a periodic assessment of lactate concentrations resulting from pulling and kicking as well as swimming.
Coaches may desire to change the training program of swimmers who have a particularly strong or weak kick. For example, a two-beat kick distance freestyler needs less energy than a six-beat distance kicker. Therefore, the two-beat kicker may require less high intensity kicking and more low intensity kicking for optimum conditioning with more emphasis on pulling. Likewise, a sprinter would need to have more high intensity kicking incorporated into his or her workout. Coaches too, should consider the potential lactate levels resulting from pulling and kicking sets and the potential influence of these lactate levels on the overall training objective. They should be aware that kicking and pulling sets are an important but demanding part of the workout and should not be considered as entertainment or a "break" from the rest of the workout. Coaches should be aware that the degree of intensity of the kicking or pulling will have an impact on subsequent swimming sets, therefore, variations in intensity should be wisely incorporated into the workout as a whole, or if necessary, a recovery period should be provided following an intense effort in order to allow lactate levels to decline.

References

Characteristics of the Front Crawl Techniques of Swimmers With Shoulder Impingement Syndrome

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Abstract
During the last ten years, shoulder pain has become increasingly prevalent among competitive free style and butterfly swimmers. The purpose of this study was to determine whether swimmers with phase I shoulder impingement syndrome (SIS) use front crawl techniques that differ significantly from those of swimmers without SIS. Eleven injured and eleven non-injured swimmers were filmed performing 25 yd free style breathing and non-breathing sprints. Three variables were measured: body roll, completion of arm pull, and height of the elbow during recovery. The injured group had a significantly greater body roll during breathing trials than during non-breathing trials. For the non-injured group, there was no significant difference between the mean values for the maximal body roll for breathing and non-breathing trials. The injured group appeared to have inconsistent rolling techniques because they had quite different maximal body roll means for the breathing and non-breathing trials. The findings of this study, and the fact that body roll has been implicated in previous studies of SIS, suggest that swimmers should develop a body roll technique which is the same for both breathing and non-breathing cycles.

Key Words: Swimming, shoulder impingement syndrome, biomechanics.

Introduction
During the last ten years, shoulder pain has become increasingly prevalent among competitive swimmers (3,4,6,7,17). This increase in the frequency of shoulder pain is most likely due to corresponding increases in the distance swum in practice and in the intensity of practice (4,14). In addition, competitive swimmers now start training at a much younger age than they did 10 years ago (4).

Shoulder problems occur predominantly among swimmers who compete in freestyle and butterfly events (4,5,10,11,14). Problems also occur occasionally among those who compete in backstroke events (4,8,9,10,11,14). Because most competitive swimmers spend at least half of their practice time performing the front crawl stroke, this stroke might well account for the injuries sustained by swimmers who specialize in other competitive strokes (14).

The most common shoulder injury found among swimmers involves the supraspinatus tendon. In the front crawl stroke, the shoulder is often forced into extreme abduction, forward flexion, and internal rotation at hand entry. This position forces the supraspinatus tendon against the coracoacromial ligament (4,8,10). At the completion of the arm pull, the shoulder is in an adducted position. In this position, the supraspinatus tendon is stretched over the head of the humerus and its blood supply is cut off (8,10,16). Thus, extreme adduction can also irritate the supraspinatus tendon. Pain associated with the pinching of the supraspinatus tendon and the blocking of its blood supply is referred to as shoulder impingement syndrome (SIS) (2,8,12,13,15,17).

Blazina (1) defined three phases of injury for use in categorizing knee injuries. These phases, based on symptoms and functional impairment, can also be used to categorize SIS (3,5,9,10). The three phases are:
1. The pain occurred only after the activity and there was "no undue functional impairment".
2. The pain occurred during and after the activity and the athlete was "still able to perform at a satisfactory level".
3. The pain occurred during and after the activity and was more prolonged than the pain in phase 2. The athlete found difficulty performing "at a satisfactory level".

Several investigators have tried to determine which characteristics of a swimmer's technique cause SIS (2,14,17). The characteristics investigated have included the arm pull, the arm recovery, the breathing technique,
and the body roll—all of which can influence the magnitudes of the shoulder abduction, forward flexion, and adduction that occur during the stroke.

These previous investigators have relied on surveys and subjective (or qualitative) evaluations of underwater photographs. None, it appears, have attempted to quantify the influence of technique on the occurrence of SIS.

**Purpose**

The purpose of this study was to determine whether swimmers with phase 1 shoulder impingement syndrome use front crawl techniques that differ significantly from those of swimmers without shoulder impingement syndrome.

**Methods**

**Subjects**

Two groups of subjects were selected—an injured group and a non-injured group. Fifteen swimmers who were suffering from shoulder pain but were practicing with their teams, volunteered for the injured group.

The fifteen swimmers were given an examination by a physical therapist well-familiar with the symptoms of SIS. The physical therapist was asked to determine whether the swimmer had SIS and, if so, the severity (phase) of the condition.

Only those swimmers with phase 1 SIS were retained in the injured group. Because these swimmers did not experience shoulder pain during practice (1), it was assumed that they did not modify their strokes due to pain.

Eleven of the fifteen volunteers for the injured group were diagnosed as having SIS. The remaining four had different shoulder conditions and were eliminated from the study.

After these eleven subjects had been identified, eleven swimmers without SIS or any other shoulder condition were selected to constitute the non-injured group. These latter subjects were selected to match those in the injured group with respect to sex and competitive level. Each of the injured and non-injured groups thus consisted of two female high school swimmers, four male collegiate swimmers, four female collegiate swimmers, and one female graduate student who had competed in swimming as an undergraduate. All swimmers were training for an upcoming competition.

**Protocol**

Each subject's arm length—the distance between the acromion process and the olecranon process—was measured to the nearest millimeter before any trials were performed. The subjects were then asked to perform six 25 yd front crawl swims at the pace they would use if asked to swim six 25 yd sprints in practice. For the even-numbered trials the subjects were asked not to breathe during the first 20 yd of the swim. For the odd-numbered trials the subjects were asked to breathe during every stroke cycle. The subjects were filmed between the 10 and 15 yd marks of the swim. To minimize the effect of fatigue, the subjects were given 2-3 min. of rest between trials.

The subjects were asked to breathe only on their preferred breathing sides. Some authors have stated that swimmers who breathe bilaterally—that is, who breathe on one side and then on the other—have less chance of developing SIS (2,14). Because not all of the subjects were experienced at breathing bilaterally, all swimmers were asked to breathe only on their preferred breathing sides. Swimmers inexperienced in bilateral breathing might have modified their strokes in attempting to learn this technique.

The subjects were filmed from the side for the first four trials and from the front for the final two trials. For those trials filmed from the front, a balsa wood fin mounted on a curved aluminum base was strapped to the back of the subject. This fin was centered on the back of the subject just below the shoulder blades. Two velcro straps encircled the subject's torso and held the fin securely in place.

![Figure 1. Arm pull and arm recovery measurements: (A) arm position at the start of the push phase, (B) elbow exit angle, (C) elbow height](image-url)
Stroke Characteristics Studied

Three characteristics of the stroking techniques employed by the subjects were selected for examination:

1. The maximal body roll. The maximal angular displacement of the shoulders from the transverse horizontal during the course of a stroke cycle.

2. The completion of the arm pull. (a) The time from when the arm (upper arm only) was vertical in the water—Figure 1A, until the hand left the water (push phase), and (b) the angle of the forearm to the horizontal immediately before the elbow left the water (elbow exit angle)—Figure 1B.

3. The maximal height of the elbow. The maximal height above the water surface attained by the elbow during the recovery phase of the stroke—Figure 1C.

These stroke characteristics were measured on the preferred breathing (open) side, and the non-preferred breathing (closed) side.

Data Collection

Two, 16 mm motion-picture cameras were used to record the performance of each subject on each trial—one to record the activity of the subject below the water surface and the other to record the action above the surface. A half-periscope system was used to obtain the underwater view (Figure 2).

![Figure 2. Half-Periscope: (A) tripod, (B) camera, (C) PVC tubing frame with plexiglass mirror at 45 deg to horizontal](image)

During the first four trials, the cameras were set on the side of the pool and the subject swam down the center of a lane 9.4 m from the center of the mirror. A linear scale was filmed above and below the water surface. During the final two trials, the cameras were positioned at one end of the lane and the subject swam toward the cameras.

Data Reduction

The film was projected from above onto a flat, white surface. Measurements of heights and angles were made from tracings of the image appearing on the white surface.

*Body Roll.* A line drawn perpendicularly through the black lines on the front (or near) edge of the fin, and the angle $\alpha$ it formed with the vertical, were used to establish the amount of body roll. Assuming that the fin was perpendicular to the shoulder line of the body, the angle $\alpha$ thus measured was equal to the angle the shoulder line of the body formed with the horizontal (Figure 3).

![Figure 3. Measurement of the amount of body roll](image)

For purposes of analysis, the body roll was considered to begin with the frame in which a hand was shown entering the water, and to end with the frame in which the same hand was shown leaving the water. The time that elapsed from the hand entering the water until the instant at which the maximal body roll angle was attained was expressed as a percentage of the total time for the body roll.

*Arm Pull.* The extent to which the swimmer completed his/her arm pull before elbow exit was referred to as the elbow exit angle. To establish the elbow exit angle, dots were placed on the projected images of the elbow and wrist at the estimated locations of the transverse axes of these joints in the last frame before the elbow left the water. A line was then drawn connecting these dots. The angle this line formed with the horizontal was defined as the elbow exit angle (Figure 1B).

The arm pull analysis also involved temporal measurements. For this purpose, the arm pull was defined in the same manner as the body roll. Two frames from the arm pull were found:

1. the frame in which the elbow exit angle was measured, and
2. the frame in which the arm was vertically positioned in the water.
The frame when the arm was vertically positioned in the water (Figure 1A) was used to define the start of the push phase in the arm pull—that is the portion of the arm pull when the arm moved from the vertical position until the hand exit position.

**Arm Recovery.** The height of the elbow axis of the arm nearer the camera, relative to the surface of the water (Figure 1C), was recorded for each frame. This height was then converted to real-life units. The real-life units were then divided by the subject’s arm length to normalize the data. The values for all subjects could then be compared.

The arm recovery analysis also involved temporal measurements. For this purpose, the arm recovery cycle was considered to begin with the frame in which the hand was shown leaving the water, and to end with a frame in which the same hand was shown entering the water. Two frames of the arm recovery were found:

1. the frame in which the maximal elbow height was recorded, and
2. the frame in which the hand first led the elbow.

The time that elapsed from the beginning of the arm recovery cycle (hand leaving the water) until each of these frames was exposed was then expressed as a percentage of the duration of the arm recovery cycle. Thus, for example, if the maximal elbow height was recorded halfway through the recovery and the hand first led the elbow two-thirds of the way through the recovery, these events would be given temporal values of 50% and 67%, respectively.

**Reliability**

One trial was selected and all variables were measured on ten different days. The coefficient of variation was determined for each variable. The maximal coefficient of variation, 3.7%, occurred on the measurement of the elbow height. The coefficient of variation for all other variables was below 3.0%.

**Data Analysis**

In accord with the purpose of this study, a statistical analysis was conducted to determine if there were any significant differences between the injured and non-injured groups with respect to the variables measured. Similar analyses were also conducted between the preferred breathing (open) and non-preferred breathing (closed) sides and between the breathing and non-breathing trials, for whatever additional insight they might provide.

For each of the variables measured, an analysis of variance (ANOVA) for a three-factor experiment with repeated measures was conducted (18). For each variable, F-tests were performed to determine if there was a significant difference between the means for:

1. injured and non-injured groups,
2. open and closed sides, and
3. breathing and non-breathing trials.

F-tests were also performed to determine if there were significant differences between the means for all possible combinations of group, side, and trial. *Post hoc* t-tests were conducted whenever a significant F was obtained for tests involving more than two means.

**Results and Discussion**

Of the parameters investigated—body roll, arm pull, and arm recovery—arm roll was the only one for which a statistically significant (p ≤ .05) difference was found between the swimmers with SIS (injured group) and the swimmers without SIS (non-injured group). The results for this parameter are presented first, followed by a brief summary of the results for the arm pull and arm recovery.

**Body Roll**

The results from the analysis of variance of the maximal body roll are presented in Table 1. The results from the *post hoc* t-tests are presented in Table 2.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group (Injured, Non-Injured)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between</td>
<td>1</td>
<td>4.37</td>
<td>4.37</td>
<td>.03</td>
<td>.86</td>
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<tr>
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<td>20</td>
<td>2894.76</td>
<td>144.74</td>
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<tr>
<td>Group x Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Among</td>
<td>1</td>
<td>4.34</td>
<td>4.34</td>
<td>.03</td>
<td>.87</td>
</tr>
<tr>
<td>Within</td>
<td>20</td>
<td>3041.31</td>
<td>152.07</td>
<td></td>
<td></td>
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<tr>
<td>Group x Trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Among</td>
<td>1</td>
<td>443.14</td>
<td>443.14</td>
<td>5.98</td>
<td>.025*</td>
</tr>
<tr>
<td>Within</td>
<td>20</td>
<td>1505.70</td>
<td>75.29</td>
<td></td>
<td></td>
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<tr>
<td>Group x Side x Trial</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Among</td>
<td>1</td>
<td>.65</td>
<td>.65</td>
<td>.01</td>
<td>.92</td>
</tr>
<tr>
<td>Within</td>
<td>20</td>
<td>1392.18</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Side (Open, Closed,) |      |       |       |       |      |
| Between             | 1    | 1319.53 | 1319.53 | 8.68  | .0080*|
| Within              | 20   | 3041.31 | 152.07 |       |      |
| Trial (Breathing, Non-Breathing) |      |       |       |       |      |
| Between             | 1    | 256.82 | 256.82 | 3.41  | .08  |
| Within              | 20   | 1505.70 | 72.29  |       |      |
| Side x Trial        |      |       |       |       |      |
| Among               | 1    | 489.09 | 489.09 | 7.16  | .015*|
| Within              | 20   | 1392.18 | 69.61  |       |      |

* p ≤ .05

**Table 2**

<table>
<thead>
<tr>
<th>Breathing</th>
<th>Non-Breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injured</td>
<td>57.8</td>
</tr>
<tr>
<td>Non-Injured</td>
<td>53.7</td>
</tr>
</tbody>
</table>

* A star between two means indicates that the difference between these two was significant at the P ≤ .05 level.
**Group x Trial.** The mean for each of the two trials (breathing and non-breathing) for the injured group was compared to the mean for each of the corresponding trials for the non-injured group. Within each group, the means for each trial were also compared. The following results were found:

1. The injured group had a significantly greater maximal body roll during breathing trials ($\bar{X} = 57.8$ deg) than during non-breathing trials ($\bar{X} = 49.9$ deg)—Table 2.

2. The non-injured group did not have a significantly different maximal body roll during the breathing trials ($\bar{X} = 53.7$ deg) than during the non-breathing trials ($\bar{X} = 54.8$ deg)—Table 2.

For the injured group, the mean value for the maximal body roll was $15.8\%$ greater for the breathing trials than for the non-breathing trials. For the non-injured group, the mean value for the maximal body roll was $2.0\%$ less for the breathing trials than for the non-breathing trials. These results indicated that the injured group had inconsistent rolling techniques.

The lesser roll recorded for the injured group during the non-breathing trials is a possible cause of SIS. Penny and Smith (14) stated, that "as a swimmer breathes, rolling about the longitudinal axis is enhanced and the amount of shoulder abduction required to clear the hand above the water is lessened." This implies that the lesser roll of the injured group may thus have required an increase in shoulder abduction during arm recovery—an increase that forces the supraspinatus tendon under the anterior edge of the acromion process and may cause impingement (14).

The greater roll recorded for the injured group during the breathing trials was unlikely to cause SIS. An increased body roll is not likely to increase either abduction or adduction at the shoulder, both of which are thought to be related to SIS (13,16).

Another possible interpretation of the finding that the injured group had a greater maximal body roll during breathing trials than during non-breathing trials cannot be ignored. Increasing the body roll is thought to lessen the pain associated with SIS (14). Despite limiting the subjects selected to phase 1 SIS—in which it was assumed that pain was not involved while swimming—these subjects may have previously modified their strokes to avoid pain, either by their own choice or on instruction from a coach.

A swimmer who knew that rolling more would lessen the pain associated with SIS, would probably find it easier to concentrate on rolling during a breathing cycle than during a non-breathing cycle, because the body must roll a fair amount just to allow the mouth to clear the water. If the swimmer does not have to think about breathing, it is possible that he/she may not think about rolling.

The results of the present study have shown that swimmers with phase 1 SIS roll less consistently than do swimmers without SIS. The rolling technique employed has also been implicated as a possible causal factor in SIS by other investigators (14). According to the results of a questionnaire study by Richardson et al (17), the majority of swimmers with SIS are sprinters and middle distance swimmers. To date, however, there appears to be no evidence of a relationship between the rolling technique used and the event classification (sprint, middle distance or distance) of the swimmers.

It might be that sprint and middle distance freestyle swimmers have different rolling techniques than distance freestyle swimmers. In competition, and on occasion in training, the former perform several complete stroke cycles without breathing and thus, for these cycles, do not need to roll as much as distance swimmers who typically breathe on each cycle. The former also use higher stroke frequencies which might conceivably cause them to reduce the range of their rolling motion compared with the latter. It might also be that the rolling technique used and the classification of the swimmer are factors that each have an influence on the development of SIS quite independent of the other.

For the present, the resolution of this question must await the results of some future study in which the rolling techniques of swimmers in different distance categories are compared. In the meantime, it would appear to be prudent for coaches to check periodically the techniques used by their sprinters to ensure that they maintain the same range of rolling motion when not breathing as they use when breathing.

No significant difference was found between groups for the instant at which maximal body roll occurred.

**Side.** The mean for the open side was compared to the mean for the closed side for the total group of subjects (injured and non-injured subjects). A statistically significant difference was found between the mean side values of maximal body roll. The subjects were found to roll—that is, to rotate the fin—more toward the closed side ($\bar{X} = 57.9$ deg) than toward the open side ($\bar{X} = 50.2$ deg). This result was expected especially during the breathing trials, because the body had to roll a fair amount to allow the mouth to clear the water.

**Side x Trial.** The mean values for the maximal roll to the open side and the maximal roll to the closed side for the total group were compared for each trial. The maximal body roll mean was significantly greater when the subjects swam a breathing trial and the fin rotated toward the closed side ($\bar{X} = 62.0$ deg) than when the subjects swam a breathing trial and the fin rotated toward the open side ($\bar{X} = 49.5$ deg)—Table 3. The maximal body roll mean was significantly greater when the subjects swam a breathing trial and the fin rotated toward the closed side ($\bar{X} = 62.0$ deg) than when the subjects did not breathe and the fin rotated toward the closed side.
(X = 53.8 deg)—Table 3. When the head turned to breathe the body naturally rolled toward the closed side to help clear the mouth from the water.

<table>
<thead>
<tr>
<th>Breathing</th>
<th>Non-Breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Side</td>
<td>49.5</td>
</tr>
<tr>
<td>Closed Side</td>
<td>62.0</td>
</tr>
</tbody>
</table>

* A star between two means indicates that the difference between these two was significant at the P ≤ .05 level.

Table 3
Maximal Body Roll Means For The Sides (degrees)

Arm Recovery and Arm Pull

One statistically significant result was obtained in the analysis of arm recovery—Table 4. The total group of subjects attained a greater height with the elbow of the open side arm than with the elbow of the closed side arm during breathing trials.

There were no statistically significant results obtained from the arm pull analysis.

<table>
<thead>
<tr>
<th>Breathing</th>
<th>Non-Breathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Side</td>
<td>.0076</td>
</tr>
<tr>
<td>Closed Side</td>
<td>.0063</td>
</tr>
</tbody>
</table>

* A star between two means indicates that the difference between these two was significant at the P ≤ .05 level.

Table 4
Means of Maximal Elbow Height in Arm Recovery Divided by Arm Length

Implications

On the basis of the results obtained in this study, it appears that coaches would do well to emphasize the importance of body roll in the front crawl. Particular attention should be paid to sprinters and middle distance swimmers, who tend to have shoulder problems more often than distance swimmers (17).

Secondly, coaches might also encourage their swimmers to learn to breathe on both sides (bilateral breathing technique). Although bilateral breathing was not included in this study, it does appear from previous studies to lessen the risk of shoulder problems (2,14). If a swimmer learns to breathe on both sides, he/she must learn to roll to both sides to let the mouth clear the water during breathing cycles. This bilateral rolling technique during breathing cycles may then be transferred to non-breathing cycles.

Suggestions for Further Study

The following suggestions for further study appear worthy of consideration:

1. Divide the injured group according to whether the injury is on the open or closed side;
2. Include measurements of shoulder and scapular flexibility and determine the influence of these values on shoulder movement;
3. Quantify the movements of the shoulder throughout the arm cycle.

Acknowledgements

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