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*Effects of a carbohydrate/protein beverage on cycling endurance and muscle damage, 2004 (M.J. Sandefur, M.D. Kim, M.K. Tully; James Madison University).

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2004, The Year in Review

Yes, the end of the year is behind us, it came more quickly than we would have liked. The question at hand is, “how are we doing?” By this I mean ‘we’ in the ‘royal we’ or rather, we who are involved in competitive swimming?

My view would be that ‘we’ as in ‘we swimmers,’ are doing very well indeed! Thank you very much! After much trepidation about the venue and security at the Olympic games in Athens, the Olympic swimmers put on a swim clinic and demonstrated once again that swimming is exciting and does draw the interest of millions of people worldwide. Without a doubt, the outcome of the 2004 Games would suggest that the number one swim team in the world is Team USA. Certainly, it is clear that there is ever increasing competitiveness throughout the world. The Japanese team demonstrated surprising successes. The South African sprinters also displayed unanticipated speed! Perhaps ‘we’ in the USA should consider the warning of baseball great Satchel Page, “Don’t look back. Something might be gaining on you.”

There is nothing wrong with great competition. It is a coaching tenet that great competition in practice leads to great competition in a meet. It keeps you from stagnation and forces you to stay focused on the ultimate goal. During the year 2004 we have been held witness to plenty of great swimming competition!

After a successful USA Olympic Trials, that was once again, perhaps the most competitive swim meet in the world, the Athens Games became a showcase for competitive swimming. There were records set, rule controversy, competitive drama, and just flat out racing. Then two moths later, Indianapolis hosted the World Short Course Championships. For those lucky enough to be in attendance, there was not much to say other than “wow!” It was clear that competition wasn’t as crisp or intense as in Long Beach or in Athens, but it cannot be denied that the venue was perhaps as spectacular as any competitive venue ever built. Walking into the building sent shivers down to one’s flippers and simply entering the competition hall was a spiritual experience. Yes, I have to say, we are doing well.

It is hard to pin point the base of this success. Without age group coaches and swimmers, there would be no senior swimmers to applaud. Without high school and college coaches, in many cases nearly volunteers, who would maintain all of this excitement? Supportive parents are key for several obvious reasons and we cannot forget the administration, management, and officials who spend endless hours to ensure that there is safe and fair competition. Thanks go out to all and congratulations to each of you who are intimately or even remotely involved in making swimming a success.

This issue of the JSR has been a long time coming. Perhaps this reflects the limited financial resources that are available for those interested in pursuing research in swimming? The policy enforced here, is that the JSR will be published when there is enough good science available to present. Certainly it should be recognized that the number of manuscripts published are in proportion to the amount of research performed and perhaps the global interest in swimming. With 2004 behind us and the competitive successes and interest evident, maybe this will act to spark further investments in the research that pertains to swimming and swimmers. Thanks are extended to all of the authors and reviewers, editors and support people who have helped put this issue together. You were all critically important in this process. And, as always, we applaud ASCA and John Leonard for providing the necessary capital!

J.M. Stager
Psychophysiological Effects of Competitive Stress on Swimming Coaches

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Abstract

Competitions may cause stress and anxiety to athletes and their coaches. The effect of psychological stress on salivary cortisol concentration was studied in eight coaches during a national swimming championship. Saliva samples were collected at four time points (fifteen days before and on three days during the championships) and analyzed for salivary cortisol. Additionally, the subjective ratings of perceived psychological arousal were measured on three days during the championships. No statistically significant changes were found in salivary cortisol concentration and cognitive anxiety during the championships. Conversely, a significant decline in somatic anxiety was observed from the beginning to the end of the championships. The temporal development of the anxiety experience supports the multidimensional anxiety theory. The findings are discussed in the specific context of swimming.

Index Terms: Cortisol, anxiety, competition, coaching, CSAI-2

Introduction

Competitive sport activities may cause stress to participants and their coaches. When a person attributes a great subjective importance to the result of an athletic event, stress increases (18). Hans Selye, the pioneer in the study of stress, defined it as a "non-specific response of the organism to any request made upon it" (27). Stress is a complex psychophysiological process, often causing marked emotional, cognitive and physiological changes (25). Anxiety is a psychological manifestation of stress (29).

Since the 1960s, an idea has started to develop that anxiety may be a multidimensional phenomenon with at least two dimensions: cognitive and somatic (5,17,19,23). Cognitive anxiety is the mental component of anxiety caused by negative expectation about success or negative self-evaluation. Worry, negative self-talk, and unpleasant visual imagery characterize cognitive anxiety (23). Empirical evidence has not provided a stable pattern of cognitive anxiety influence on sport performance. A number of studies have reported a negative relationship between cognitive anxiety and performance (2,3), while there is also evidence supporting a positive relationship (32,33). Somatic anxiety, on the other hand, is the physiological or affective component of anxiety that is directly related to autonomic arousal. Somatic anxiety is reflected in such responses as rapid heart rate, shortness of breath, clammy hands, butterflies in the stomach, and tense muscles (21). A number of methodologies have been developed attempting to estimate the various aspects of anxiety in sport including self-report measures, biochemical and physiological indices. Research findings have indicated inconsistent patterns of response between psychological and physiological measures of anxiety (4,13,22). Thus, the use of multiple methods is necessary for a more complete estimation of anxiety (7,9,24).
In order to estimate competitive anxiety multidimensionally, a valid and reliable self-report tool was developed; namely, the Competitive State Anxiety Inventory–2 (CSAI-2) (3,19). This inventory evaluates the participants' self-reported cognitive anxiety (cognitive A-state), the perception of their physiological responses, or somatic anxiety (somatic A-state), and self-confidence. Self-confidence, as conceptualized by Martens and coworkers (21), refers to the positive thoughts and expectations from involvement with the task at hand. Research evidence with Greek athletes has supported the inventory's ability to assess cognitive and somatic anxiety effectively, while the self-confidence subscale has received criticism (31).

The most commonly used biochemical index of anxiety is the steroid hormone, hydrocortisone (cortisol), which is secreted by the adrenal cortex under the influence of the hypothalamo-pituitary-adrenal axis in response to a multitude of psychological stimuli (14). The concentration of cortisol in saliva has been shown to correlate well with its concentration in plasma (26). A number of studies reported increased salivary cortisol concentrations in athletes after exposure to acute stress, such as competition (1,6). Elite golfers experienced elevated cortisol during competition compared to practice (22). On the other hand, repeated daily stress events, such as public speaking for five days, resulted in consistently higher levels of salivary cortisol compared to baseline (15), while the mean excretion rate of cortisol on three working days was higher than baseline in long-distance coach drivers (28).

The psychological response of coaches to the acute stress of a competition has been evaluated in the past (16,20). However, there are no published studies specifically addressing the responses of coaches to repeated daily stress events. Moreover, although there is substantial research on the effect of competition importance on precompetitive anxiety (30,33), there has been limited use of physiological estimates of state anxiety (6). Therefore, the aim of the present study was to investigate the psychophysiological responses of swimming coaches experiencing 5 days of competitive stress and the relation of these responses to the perceived importance of competition.

Methodology

Participants

Eight apparently healthy male professional swimming coaches, aged 26–40 years (mean, 33.0), participated voluntarily in the study. They were on no medication and only one was a smoker. The coaches were recruited from among ten head coaches of swimming clubs in Thessaloniki, Greece. Coaches' experience with athletes competing at the national and international levels ranged from 5 to 14 years. They coached male and female age-group swimmers who had been chosen to compete at the national swimming championships. Their teams ranked between the 3rd and 16th places at the particular championships. Informed consent was obtained from all subjects. The study was designed and carried out according to the guidelines of the University of Thessaloniki Ethics Committee and the Declaration of Helsinki.

Materials and procedures

For cortisol determination, subjects provided four saliva samples, i.e., one fifteen days before competition (pre-stress baseline), one on the first day, one on the third day and one on the fifth (final) day of the national swimming championships. To this effect, participants were asked to chew a plain cotton swab (Sarstedt, Nümbrecht, Germany) for one minute. Subjects consumed no coffee and did not smoke for six hours before sampling. The swab was then placed in a special centrifuge tube (salivette) holding the swab in a suspended insert well above the bottom. The tubes were frozen at −20°C to precipitate mucins. To control for diurnal variation in cortisol concentration, all samples were taken at the same time of the day, i.e., shortly before 5 p.m., which was the time that the events started during the championships.

Immediately following each of the three saliva samplings during the championships and minutes before the start of the events, multidimensional state anxiety was assessed using the Greek version of CSAI-2 (31). The inventory consists of two factors, i.e., somatic anxiety and cognitive anxiety, with nine items for each factor. Then, just before the start of the events, the perceived importance of the particular day's events was rated on a four-point Likert-type scale ranging from 1 (not at all) to 4 (very much so).

For cortisol determination the specimens were thawed completely and centrifuged at 1500 x g for fifteen minutes to produce approximately 1 mL of clear saliva. Cortisol was assayed by using an enzyme immunoassay kit from Salimetrics (State College, PA).

Statistical analysis

Descriptive statistics (minimum, maximum, mean and standard deviation) of the variables are reported. Comparisons with respect to cortisol concentration, Likert-type scale and subcomponents of CSAI-2 were carried out through one-way Friedman ANOVA. Correlations between variables were examined by Pearson's correlation analysis. The level of statistical significance was set at a = 0.05. Data were analyzed with SPSS 10.

Results

The descriptive statistics of the variables tested in the study are shown in Table 1. Mean salivary cortisol of the coaches ranged from 0.21 μg/dL at pre-stress baseline to 0.33 μg/dL at the end of the championships (Figure 1). Most of the 32
Table 1. Descriptive statistics of the study variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-stress salivary cortisol (µg/dL)</td>
<td>12</td>
<td>20</td>
<td>21</td>
<td>0.91</td>
</tr>
<tr>
<td>Cortisol (day 1) (µg/dL)</td>
<td>13</td>
<td>23</td>
<td>21</td>
<td>0.66</td>
</tr>
<tr>
<td>Cortisol (day 3) (µg/dL)</td>
<td>15</td>
<td>24</td>
<td>22</td>
<td>0.44</td>
</tr>
<tr>
<td>Cognitive anxiety (day 1)</td>
<td>12</td>
<td>17</td>
<td>15.38</td>
<td>1.77</td>
</tr>
<tr>
<td>Cognitive anxiety (day 3)</td>
<td>13</td>
<td>19</td>
<td>15.91</td>
<td>1.79</td>
</tr>
<tr>
<td>Cognitive anxiety (day 5)</td>
<td>9</td>
<td>20</td>
<td>16.12</td>
<td>4.02</td>
</tr>
<tr>
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<td>13</td>
<td>22</td>
<td>16.82</td>
<td>3.61</td>
</tr>
<tr>
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<td>11</td>
<td>19</td>
<td>17.27</td>
<td>2.03</td>
</tr>
<tr>
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<td>12</td>
<td>17</td>
<td>13.75</td>
<td>1.83</td>
</tr>
<tr>
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<td>2</td>
<td>3</td>
<td>3.75</td>
<td>0.46</td>
</tr>
<tr>
<td>Competition importance (day 3)</td>
<td>2</td>
<td>4</td>
<td>3.00</td>
<td>0.53</td>
</tr>
<tr>
<td>Competition importance (day 5)</td>
<td>1</td>
<td>4</td>
<td>3.13</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Figure 1. Subcomponents of CSAI-2 during days 1, 3 and 5 of the swimming championships: somatic anxiety (open bars), and cognitive anxiety (slidet bars).

Individual values were within the normal range for the general population (0.02 - 0.36 µg/dL; ref. 14). Five values obtained during the championships were above this range. No statistically significant changes were found (p = 0.16). Likewise, the perceived importance of the events that took place during the first, third, and fifth day of the championships showed a trend (Figure 2), but the results were not significant (p = 0.15). A significant decline in somatic anxiety was observed from the beginning to the end of the championships (p = 0.017, h² = 0.61; Figure 3) but no significant changes were found in cognitive anxiety (h² = 0.13). Finally, correlation analysis revealed only one significant correlation, i.e., between cortisol and somatic anxiety on the third day of the championships (r = 0.84, p < 0.001).

Discussion

The performance and rank of swimmers, as well as the ranking of the team are the main concerns of swimming coaches in a national championship. The aim of the present study was to examine psychophysiological manifestations of stress in swimming coaches during such a championship. The findings from the present study indicate that there were no significant changes in salivary cortisol levels, cognitive anxiety and perceived importance of the competition. As far as cortisol is concerned, research in soccer coaches has shown that cortisol concentration increased as a result of competition and normalized after one hour (16). Similarly, Kirschbaum and coworkers (15) reported that, although salivary cortisol levels were significantly elevated on each of 5 days of exposure to the same daily psychological stressor (public speaking), the mean response decreased from day 1 to day 2 and did not change during the remaining days. This is similar to the findings that drivers of motor coaches had higher salivary cortisol concentrations on all three working days in comparison to baseline and a trend towards accumulation of cortisol from the first day to the third working day (28).

The contradiction between the present study and the studies of Kugler and coworkers (16), as well as Kirschbaum and coworkers (15), could be explained by the different degree of threat experienced by the swimming coaches. At the national championships of swimming, the competitions that would determine the rank of the athlete and the team were scheduled for the final two days. This might have provided swimming coaches with sufficient time to cope with the experience of anxiety and have a cortisol response not significantly different from the response to a routine training day.

As far as the dimensions of state anxiety are concerned, the findings of the present study revealed that somatic anxiety peaked at the beginning of a championship and decreases subsequently, whereas cognitive anxiety remained relatively
stable in a way similar to temporal patterning prior to a single competition. These findings are similar to those reported in the literature (8,10,11) and imply that during championships coaches maintain their expectations for success or have sufficient time to cope with changes in success expectations.

Although the most significant competitions were at the end of the championships, the perception of competition importance did not increase significantly with time in our study. This is difficult to explain. A possible reason could be that a defensive mechanism developed in order to excuse possible failure. Furthermore, methodological issues regarding the use of a single item to estimate perceived importance may have led to these results.

Correlation analysis revealed that the importance of competition was not related to the variables of state anxiety or cortisol. These findings are in contrast to those of Jones and coworkers (12), who reported that importance of competition is a significant predictor of cognitive anxiety. Furthermore, the present study did not reveal significant correlations between cortisol concentration and the state anxiety variables (with one exception, i.e. between cortisol and somatic anxiety on the third day). These findings are similar to those reported in the literature (4,13), indicating that physiological and psychological measures of anxiety are not necessarily related.

A limitation of the present study was the small sample size—which has been primarily dictated by the small number of available head coaches in the particular environment—and the resulting low power of the analysis (approximately 0.1). This might have been the reason why some of the visible trends have not produced significant differences or correlation. It is therefore possible that a larger sample size would have yielded different results. Within this limitation, our results imply that repeated daily stress events may not influence the majority of psychophysiological measures of anxiety in swimming coaches.

Applications

The present study revealed important directions regarding future research with swimming coaches. For example, it would be interesting to examine the effect of athletes' success and failure on the construction of a coach's expectations and anxiety. Furthermore, the study of anxiety levels during training periods would be very interesting. Training periods may be extremely stressful for coaches as well as athletes, since coaches experience daily concerns regarding the load and intensity of the training program, the adaptations of the athlete and a number of peripheral issues that affect the athlete's training and subsequent performance, such as physiotherapy, nutrition, medical examinations etc. The study of possible variations in psychophysiological measures of anxiety with training period may prove useful in improving coaching efficiency and hence increase performance of the athlete.

References


A Comparison of Selected Kinematic Variables Between Races in National to Elite Male 200 m Breaststroke Swimmers

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Abstract

The aim of this study was to compare the kinematic and temporal responses of national to elite breaststroke swimmers from two competitive races where finishing times differed by approximately 1.9%. Two, 200 m international breaststroke races were compared for 36 swimmers. In the faster race, significantly lower times were observed for the start time to 15-m and for each of the turning times. Mid-pool swimming velocities were also greater for all lengths. A non-significant increase in stroke rate and stroke length was also observed. The change in swimming velocity, turning times and start time accounted for approximately 60%, 34% and 5% of the difference in race finishing times respectively. In both races a positively split pacing strategy was observed and there was evidence that pacing was more positive in the faster race. Elite 200 m breaststroke swimmers improve their race performance through a combination of increasing swimming velocity and decreasing starting and turning times, therefore coaches need to emphasize a systematic approach with regard to race preparation.

Index Terms: Starts, turns, stroke rate, stroke length, swimming velocity

Introduction

Sophisticated video playback, digitizing, and computer analysis techniques have been used to measure stroke rate, stroke length, and mid-pool swimming velocity during swimming competitions (6, 2). Additionally, temporal variables such as the time taken to reach a set distance from the start of the race, the time for the ingress and egress of each turn (turn time) and the time taken to complete the final 5 m of the race (end time) have been reported (16, 11).

Arelano et al. (1) suggested that start time, turn time, and end time had a direct bearing on race outcome in the freestyle events at the 1992 Barcelona Olympic Games. Thompson et al. (11) have since reported that mid-pool swimming velocity, turn time and start time are highly correlated with finishing time in both the 100 m and 200 m male and female breaststroke events. Stroke rate and stroke length have been found to be poorly correlated with breaststroke performance (5, 11), possibly because breaststroke swimmers exhibit unique stroke rate-stroke length ratios (12).

At the present time, it remains unclear how an individual’s stroke rate and stroke length responses change when a race performance improves. McMurray et al. (9) reported that improving collegiate breaststroke swimmers demonstrated a reduced number of strokes for a given swimming speed, over the course of a competitive season, which would suggest that stroke length increased during better race performances. Unfortunately the swimmers in this study were required to count their own strokes which may have resulted in significant measurement error. Furthermore, no mention was made as to whether half strokes were counted or not.

What differentiates a faster race from a slower one, in terms of kinematic and temporal variables, has not been well documented. Therefore it remains difficult for coaches to provide advice to swimmers about which race element, or elements, to attempt to improve over consecutive competitions and which may have the most potential to impact on performance. The aim of this study was to compare the kinematic and temporal responses of national to elite breaststroke swimmers from two
competitive races, where a true performance change had occurred, in order to identify which of the variables changed and to what degree.

**Methodology**

**Participants**

Participants (N=36) were A and B finalists in men’s 200 m breaststroke events competing in either world, international and national championships over a 6 month period. Participants were chosen on the following criteria. First, that the performance measured was in a final rather than a heat performance, to ensure a maximal effort had occurred. Second, that the participant’s finishing time differed by at least 1.8 % between the two races to be analyzed. This was because pacing error due to biological (within swimmer variation) or technical (measurement) error can lead to variability in human performance on a day-to-day basis. For example, New Zealand junior and open national standard swimmers have been observed to exhibit a variability of between 1.3-1.5 % between competition performances over 20 day period (10). Thompson et al. (13) also reported that senior non-elite swimmers demonstrated a 1.3 % error in pacing over a 175 m breaststroke trial, even when the effort was externally paced. It is likely that pacing error would be greater during an actual competition as the degree of positive pacing observed during senior breaststroke races is often quite exaggerated (12). Consequently, in the present study it was decided that only race performances where a difference of approximately 1.9 % between races had occurred would be included in the analysis, to be reasonably certain that a true improvement in performance had occurred.

**Measurements**

Five fixed panning cameras (Sony G100, 50 Hz) filmed each race from high vantage points perpendicular to markings at 5 m, 7.5 m, 15 m, 25 m and 42.5 m along the length of the pool-side (Fig 1). Each portion of a race was filmed in sequence by an experienced technician who followed each race and switched from one camera to the next, at each change over point. This allowed a recording to be made onto a single video tape. The final 5 m of the race (the end time) was recorded by camera 1, the turn time (7.5 m into the turn and back out to 7.5 m from the turn) by camera 2, the start time (dive start to 15 m) by camera 3, and the mid-section of each length to determine mid-pool swimming velocity and stroke rate was recorded by camera 4. The turn times at the opposite end of the pool were recorded by camera 5. A video playback system was interfaced with a computer and controller circuit board (Mnf. Professor Haljand, Tallin University, Estonia). Video frames were sequentially encoded to allow the computer to detect the frame being played back. The computer then measured the time taken for a swimmer to move a known distance in the pool by counting the requisite number of frames (each frame representing 0.02 s).

At 5 m, 7.5 m, 15 m, 25 m and 42.5 m digital lines were superimposed onto the video playback using pool-side calibration markings. The start time measurement began with the starting signal which activated the timing system and ended when the swimmer’s head touched the superimposed digital line at 15 m from the start. End time began to be measured when the swimmer’s head touched the digital line 5 m from the end wall. An assumption was made that the swimmer’s head was 0.5 m behind the wall at the moment the hand touched it, which meant that the head had moved 4.5 m. By knowing the head’s velocity over 4.5 m it was possible to calculate the time it would take to travel 5 m at that velocity. The time taken for the swimmer’s head to touch a digital line 7.5 m from the end wall and to return to the same point was used to determine the turn times. A mean turn time was calculated from turns made at 50 m, 100 m and 150 m.

When the swimmer’s head reached a digital line at 25 m along the length, the stroke rate was calculated from the number of frames required to complete a stroke cycle. The time taken for the swimmer’s head to travel from the 15 m line to the 25 m line and from the 25 m line to the 42.5 m line was used to calculate the mid-pool swimming velocity. Using the formula: stroke length (m) = swimming velocity (m.s-1)/ stroke rate (cycles.s-1), stroke length was then calculated. Mean values for mid-pool swimming velocity, stroke rate and stroke length were calculated for each race.

**Statistical analyses**

Data was found to be parametric, therefore dependent t-tests and one-way repeated measures ANOVA were used to compare mean differences within variables and between races. A significance level was set at P<0.05. A post hoc test (Tukey’s HSD test) identified where significant differences occurred.
Findings

Mean finishing time decreased by 2.65 s (~ 1.9 %) in Race 2, while start time decreased by 0.13 s on average (Table 1). Mid-pool swimming velocity significantly increased in Race 2 for all lengths. The swimmers adopted a positively split racing strategy in both races, however this was slightly more exaggerated in Race 2. The increase in mid-pool swimming velocity in Race 2 accounted for approximately 1.6 s (60.3 %) of the difference in the finishing times. A non-significant trend of an increase in both stroke rate and stroke length for Race 2 was observed compared with Race 1, and led to the changes observed in mid-pool swimming velocity. Mean turn time decreased in Race 2. Reductions in individual turn times in Race 2 resulted in a reduction of 0.89 s in finishing time on average.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Race 1</th>
<th>Race 2</th>
<th>t-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finishing time(s)</td>
<td>140.46 ± 5.10</td>
<td>137.81 ± 4.45</td>
<td>7.12</td>
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<td>Start Time(s)</td>
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<td>7.55 ± 0.37</td>
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<td>Swimming Velocity (m/s²)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Length 1</td>
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<td>1.46 ± 0.05</td>
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<td>Length 2</td>
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<td>1.36 ± 0.05</td>
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<tr>
<td>Length 3</td>
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<tr>
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<td>-2.62</td>
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<td>Stroke Rate (strokes/min⁻¹)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>38.03 ± 4.51</td>
<td>39.46 ± 4.05</td>
<td>-0.84</td>
<td>0.409</td>
</tr>
<tr>
<td>Length 4</td>
<td>42.23 ± 4.69</td>
<td>42.26 ± 4.28</td>
<td>-0.04</td>
<td>0.972</td>
</tr>
<tr>
<td>Stroke Length (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length 1</td>
<td>2.25 ± 0.24</td>
<td>2.28 ± 0.23</td>
<td>-0.11</td>
<td>0.426</td>
</tr>
<tr>
<td>Length 2</td>
<td>2.20 ± 0.24</td>
<td>2.24 ± 0.25</td>
<td>0.28</td>
<td>0.603</td>
</tr>
<tr>
<td>Length 3</td>
<td>2.09 ± 0.22</td>
<td>2.09 ± 0.22</td>
<td>-0.02</td>
<td>0.948</td>
</tr>
<tr>
<td>Length 4</td>
<td>1.99 ± 0.19</td>
<td>1.99 ± 0.20</td>
<td>-0.26</td>
<td>0.826</td>
</tr>
<tr>
<td>Turn Time(s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 50 m</td>
<td>9.71 ± 0.42</td>
<td>9.40 ± 0.39</td>
<td>4.72</td>
<td>0.000</td>
</tr>
<tr>
<td>At 100 m</td>
<td>9.58 ± 0.54</td>
<td>9.38 ± 0.54</td>
<td>3.31</td>
<td>0.001</td>
</tr>
<tr>
<td>At 150 m</td>
<td>10.26 ± 0.47</td>
<td>10.05 ± 0.47</td>
<td>3.40</td>
<td>0.000</td>
</tr>
<tr>
<td>End Time(s)</td>
<td>3.31 ± 0.54</td>
<td>3.43 ± 0.29</td>
<td>1.31</td>
<td>0.140</td>
</tr>
</tbody>
</table>

Discussion and Applications

In high performance sport, understanding the impact of a particular part of a race upon race performance is vital to the process of coaching, as it allows coaches to set realistic performance goals and for the correct emphasis to be placed on individual race elements in training. The data in the present study demonstrated that when elite breaststroke swimmers improve their race performance by around 1.9 % the vast majority of that change will be through an improvement in mid-pool swimming velocity, although significant improvements would also be expected in turn times and start time, but not in end time (the time to complete the last 5 m of the race). Therefore a true improvement in performance is generally achieved by the swimmer's competency increasing in all three of the aforementioned variables, rather than in only one. Consequently, as a general rule of thumb coaches should prioritize training in the following order: swimming velocity followed by turns followed by starts for 200 m breaststroke swimmers. However, a caveat to this statement is that coaches should always compare their swimmer's performance in each of these elements against their relative world ranking, before making a final decision on where to place training emphasis. It is too simplistic to expect approximately 60%, 34% and 5% of the race performance improvement to come from increases in swimming velocity, turns and the start respectively. For example, it is quite possible for a swimmer to be relatively better than expected in terms of swimming speed when compared to a more highly world ranked swimmer but to be disproportionately slower in terms of turning times.

The findings support those of Thompson et al. (11), who found that mid-pool swimming velocity, turn time and start time, when incorporated into a regression equation, accurately predict finishing times for men's 200 m breaststroke races. Thompson et al. (12) also concluded that better 200 m swimmers demonstrate greater competency in terms of mean mid-pool swimming velocity, mean turning time and start time but not in stroke kinematics, which were found to be unique to the individual.

Many high performance coaches measure their swimmer's stroke rates and stroke counts (to estimate stroke length) as part of a race "performance analysis", because the product of stroke rate and stroke length produces the swimming velocity (4). Surprisingly in the present study, non-significant changes in stroke rate and stroke length were found despite a significant change in mean mid-pool swimming velocity between races. The data shows a non-significant increase in stroke rate which is proportionately greater than the non-significant increase in stroke length. This suggests that the change in stroke rate accounts for a greater proportion of the change in swimming velocity, although changes in both variables were subtle (~0.4-1.0 %). It is an important finding because researchers have been debating for some time whether increases in swimming velocity are achieved by an increase in either stroke rate, stroke length or both (2, 3, 5, 12). The data from this study provides evidence that increases in both stroke rate and length cause the increase in swimming velocity in national/international 200 m breaststroke races. Manley and Atha (8) suggest that during constant velocity swimming, mean stroke velocity is not dependent on the stroke rate but is dependent on the intra-stroke peak velocity. However, it is
not possible to say whether this statement is applicable to the breaststroke, as during actual breaststroke races constant velocity swimming does not occur.

There is a limitation in the way that stroke rate and stroke length were calculated in the present study. The stroke rate was measured from only one stroke cycle per length and so there is no guarantee that the stroke measured was typical of the one or two stroke cycles before or after it, although as data were averaged from 36 swimmers this would alleviate some of the possible measurement error. The stroke length was calculated from the swimming velocity and the stroke rate and so the same potential for error exists with it's measurement. During competitions, coaches tend to use hand timing to measure the swimmer's stroke rate (over 3-5 consecutive stroke cycles) and subjectively count the number of strokes per length to estimate stroke length. Using these methods, Thompson et al (14), observed random error of ± 0.5 strokes per minute for stroke rate and ± 1.3 strokes per length for stroke count during moderate to high speed breaststroke swimming. The subtle changes observed between races in these variables in the present study would suggest that the random error associated with subjective stroke counting precludes it's use by coaches to detect changes in stroke length during national / international breaststroke races. The use of hand timing to detect subtle changes in competition stroke rate measurement would also be susceptible to measurement error and should be avoided if at all possible.

The group of elite swimmers in the present study swam each race using a positively split pacing strategy. This pacing strategy is generally representative of national and international breaststroke swimmers (11). The differential in midpool swimming velocities and turn times between Race 1 and Race 2 decreased as the races progressed (Table 1). This was probably an expression of relatively greater leg fatigue resulting from the greater pace in Race 2, as it has recently been shown that blood lactate concentrations (indicative of lactic acid accumulation in the exercising muscle) can be significantly elevated through small changes in pace during high intensity breaststroke swimming (13, 15). In the same study, turn times were suggested to be sensitive to increases in lactic acidosis and notably in the present study the difference between the first and last turns was greater in the faster race, again possibly suggesting more acute fatigue was being experienced.

Summary

Coaches emphasize the importance of increasing swimming velocity through high intensity, high volume swimming and the present study supports the view that the "swimming" element of the race affords the greatest improvement in race performance. It seems that this results from breaststroke swimmers being able to increase their stroke rate and also slightly increase their stroke length. Additionally the data highlights the significance of the starts and turns and the potential for improvement they afford the swimmer. Coaches need to ensure that they allocate a sufficient proportion of training time to these elements in order to confer a performance benefit. That said it is difficult to improve on such technical components without specialist knowledge and access to biomechanical support.

Interestingly, the faster race (Race 2) was more positively split than the first (slower) race which would tend to suggest that this pacing strategy is advantageous for maximizing elite level breaststroke swimming. However, a word of caution needs to be provided here, recent studies by Thompson et al. (13, 15) suggest that an even pacing strategy might be less fatiguing than a positive pacing strategy. They observed a lower anaerobic energy contribution, perceived level of exertion and variability in turn times when breaststroke swimmers evenly paced their swims. Therefore it is worthwhile for coaches and swimmers to experiment with both even and positive pacing strategies during breaststroke competition to compare and contrast their efficacy.

Finally, the current study suggests that changes in stroke rate and stroke length are extremely subtle when small improvements in performance occur. The error inherent in subjective stroke counting means that it should not be used to determine changes in stroke length during competition swimming. Hand timing for the determination of stroke rate is also unlikely to be precise enough for the coach to provide meaningful information when providing feedback to swimmers about contrasting race performances. For swimming competitions a video analysis system and poolside or lane rope calibration markings are required to allow accurate and reliable data to be collected.

References


Rapid Correction of Start Technique in an Olympic-level Swimmer: A Case Study Using Old Way/New Way

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Abstract

This study examined the effectiveness of old way/new way, an innovative meta-cognitive learning strategy initially developed in education settings, in the rapid and permanent correction of consistent errors in starting technique experienced by an Olympic-level swimmer. Individualized intervention three days prior to the major competition included a detailed error analysis, step-wise enhancement of an athlete's kinesthetic awareness, and re-activation of the error memory, discrimination, and generalization of the individually optimal correct movement pattern. Self-reports, coach's ratings, and video recordings indicated that a single learning trial produced immediate and permanent technique improvement (85–100% correct starts), a full transfer of learning without the need for the customary adaptation period, and improved performance. The findings are consistent with performance enhancement effects of old way/new way demonstrated experimentally in other sports. Future research directions include the extension of error analysis and application of the notion of individually optimal technique based on the Individual Zones of Optimal Functioning model assumptions.

Index Terms: Old way/New way, error correction, start technique, swimming, IZOF model, performance

Errors are inseparable from human performance and performance related experiences. The most common of all performance-induced errors are learned or so-called skill-based, recurrent or expert errors (17). Learned errors interfere with athletes' skilled performance by triggering task-irrelevant focus, uncertainty, self-doubts, frustration, and lower motivation. Ineffective techniques usually demand more resources and prevent an athlete from performing up to her potential. Some of these interference effects have been well documented in different sports (3, 4, 5, 10, 12, 13, 18, 21, 23).

The coaching literature emphasises the error prevention and error avoidance ("getting it right the first time") strategies (9). However, despite quality coaching and motivated athletes, correction of erroneous technique is often ineffective because conventional skill correction methods rely mainly on skill drills (re-teaching by repetition of the right way). This practice usually involves pointing out the error, increasing an athlete's self-awareness, showing the right way and explaining why it is better, asking the athlete to copy it, providing reinforcement and corrective feedback, and then emphasizing further practice of the correct skill (16). This approach is based on the assumption that the athlete, for some reason, did not learn from the original coaching and drill sessions; so re-teaching of the skill is necessary.

It is important to realize that deliberate practice involving repetition and successive refinement is valuable and necessary for learning a new skill (7, 8). Such practice, however, is much less effective in changing or improving existing, well practiced, and automated skill, which is not under conscious control and is therefore hard to correct. The impact of learned errors is that athletes often seem to improve during training and skill drills but they become confused, make errors, and appear to forget what they have learned when they are back in the heat of competition (12, 15). They repeatedly fall back to
their old incorrect ways and fail to improve or improve only very slowly (16). Consequently, the adaptation period to a new technique or new skill is often greatly prolonged and during this period errors increase and the athlete becomes even more frustrated. It is not surprising; therefore, that coaches and sport psychologists usually do not recommend (and even avoid) any change and change-focused interventions prior to major competitions of the season.

It is well known that practicing the right technique in the face of learned error is usually time-consuming, and largely unsuccessful (5), yet coaches and athletes persist with it because there are few really practical alternatives. For instance, existing behavioural approaches to coaching (1, 19) are often not user friendly, complicated, resource consuming, and usually difficult to implement.

A new and promising alternative approach to rapid and permanent error correction in sport is the Lyndon's (14, 15) theoretical framework and a practical tool called old way/new way. It is a novel synthesis and interpretation of both established and newly emerging learning concepts and principles such as the role of automaticity in learning and behavior, the concept of learned errors (17), the impact of prior learning on learning new skills, the value of metacognitive strategies for enhancing learning, and proactive inhibitory interference and accelerated forgetting (22). Lyndon's (14,15) approach explains why habitual errors in conceptual understanding and skilled performance are so difficult to correct and offers a practical method for addressing this problem.

Briefly described, the old way/new way holds that consistent, habitual errors indicate the presence, rather than the absence, of learning. When new knowledge or a new skill disagrees or conflicts with what a person already knows, this conflict generates proactive inhibition (PI), which causes accelerated forgetting of the new information the person is trying to learn (22). PI does not prevent learning from occurring; it merely prevents the association of conflicting ideas and protects all prior knowledge, as it does not discriminate what is “right” and what is “wrong” in a given context. In other words, PI exerts a maintenance effect over prior learning, inhibiting change and preserving erroneous (as well as correct) knowledge and skills. PI is a universal and involuntary mechanism over which one has little or no control. There appear to be large interindividual differences in the inherited level of PI. Individuals with higher PI are less likely to achieve successful behavior change (error or skill correction, habit reversal) under conventional correction methods. Performance becomes cue-dependent and the individual reverts to prior behavior patterns, especially, when the coach is not present (6). This usually results in the inhibition of learning transfer to other settings (16); moreover, the erroneous knowledge and behavior continue to resist correction.

As a practical way to address this problem, old way/new way (14, 15) contrasts the erroneous and correct movement patterns following the individually tailored protocol prepared prior to an intervention, called a learning trial (LT). Experimental studies of the effectiveness of old way/new way in non-sport performance settings and the numerous field trials (2, 14, 15) consistently report that after one successful correction session the person has an 80% or higher probability of performing in the new way; and has a 90% probability of self-detecting an old way when it occurs and then self-correcting it. Spontaneous recovery of the old way can be expected at two to three weeks after the original learning trial and is effectively handled.

Rapid error correction based on the Lyndon's old way/new way has also been employed at the South Australian Sports Institute (SASI) as a practical tool rather than for research purposes. The SASI athletes included baseballers (pitching technique); basketballers (shooting technique); divers (hurdle technique on spring board, take-off technique on platform, and body posture); rowers (catch position), soccer players (kicking technique), and volleyballers (hitting and serving technique, as well as team concepts and beliefs). As predicted, the old way/new way was successful in rapid correction of learned errors. However, in most cases, time interval between intervention and competition following the LT was not the focus of the study.

Although rapidly growing anecdotal evidence is available in the form of accelerated learning and improved effect attributed to old way/new way by sport psychologists and coaches, little if any of this work has been documented. Recently, Hanin et al. (12) reported exploratory case studies involving two female Olympic athletes (javelin throwing and start in sprint) using old way/new way for rapid correction of technique. As predicted, a single LT produced immediate and permanent technique improvement (80% or higher correct action) and full transfer of learning without the need for the customary adaptation period. However, intervention with the javelin thrower was initiated three weeks prior to the World championships, whereas the sprinter did the learning trial post season. Other athletes at the KIHU-Research Institute for Olympic Sports in Jyväskylä (Finland), who successfully employed old way/new way, included hammer throwers, a golfer, and soccer players. In all cases, however, the intervention was conducted off-season or several weeks or months prior to the competition.

Therefore, the aim of the present study was to explore the effectiveness of rapid technique correction using the old way/new way methodology immediately prior to major competition of the season. Specifically, intervention was conducted three days prior to the National championships with an eight-month follow up during the competitive season. Because the old way/new way claims immediate and permanent change in behavior and performance, it would be expected that, if the LT were successful, an athlete performed 80% of correct starts in practices and immediately during the National
Championships. A permannency of technique correction should be also observed in the stability of post-LT starts later during the competitive season as the spontaneous recovery may occur after two weeks. Finally, if, according to the Individual Zones of Optimal Functioning (IZOF) model (10, 11, 12), the new start techniques were individually optimal and thus more efficient than the previous movement pattern, then the total performance of this athlete should also improve.

Method

Participant

Jack (not his real name), a 22-year-old Olympic level male swimmer, took part in this study initiated at his coach’s request. This athlete’s sporting experience was 13 years and involved participation in several international competitions (European, World Championships and Olympic games). This athlete was accepted for a study based on the criteria proposed by Hanin et al. (12): he had an established (consistent and predictable) technique problem; he was unresponsive to all previous correction attempts such as quality coaching; and it was an ongoing source of frustration for both athlete and his coach.

Background to the Technique Difficulty

In performing starts usually during a competition, Jack sometime jumped too high. This resulted in a deep dive and poor glide to the surface. Therefore Jack had to work harder to come out from the water. Usually he could not control his jump height and this error occurred both in practices and competitions. Jack and his coach tried to correct in vain the error in practices by repeating the starts accompanied by an immediate feedback from the coach. However, controlling start technique was a problem both in practices and competitions as it was a learned (automatic) error. The coach and Jack heard about the Old way/new way and decided to try it very close to the National championships as they believed this might help improve results. Coach also felt that the jump in the start would not be difficult to practice and that would do no harm to overall performance. Both had previous experience with drill-based technique correction (an error in freestyle stroke), which took several months of hard work. So at coach’s suggestion it was agreed to try old way/new way for rapid and permanent correction of this consistent error.

Measures:

Measures used in this case study included:

1. A detailed analysis by athlete and coach of erroneous and correct starts
2. Video-recordings of all starts during the learning trial (LT)
3. Transcribed tape recordings of the athlete’s self-reports after each start during the LT

4. Percentage of correct starts in the post-LT practices and during selected competitions
5. Performance outcomes (regular check-ups in practices; official starting times in competitions)
6. Observation of the athlete’s behavioural and emotional responses

Procedure

Because old way/new way is a team effort involving the athlete, the coach, and the sport psychologist acting as change facilitator, all participants contributed to the error analysis and during other stages of the LT as a skill development process. The first author, trained in old way/new way, conducted a preliminary session with the coach and then with the coach and an athlete explaining the change process and the mechanisms of the change with potential benefits of old way/new way methodology in rapid correction of starting technique. Additionally, prior to the skill correction session the volunteer aspect of the participation was emphasized and confidentiality of the results was assured. Moreover, at any time, the athlete was told he could discontinue his participation in the experiment at any time. After agreement was obtained, the athlete and coach prepared a detailed error analysis of the technique difficulty. Based on this error analysis and the recommendations developed in educational (14) and sport (12) settings, an individualized old way/new way protocol for correcting the athlete’s technique problem was devised and implemented in a single old way/new way LT lasting one and a half hours, including a warm-up period. The actual LT included four steps: improvement of Jack’s mental and physical awareness of the old and new ways; systematic and progressive discrimination of the old and new ways; and generalization or practice of the new way. After the LT, the athlete and coach were de-briefed and the strategies to enhance learning and to deal with spontaneous recovery of the error were suggested. An eight-month follow-up of the progress was conducted in subsequent practices following the performance in the National championships and during major competitions of the season.

Results

Pro-trial error analysis

In error analysis, the coach and the athlete described the technique fault by answering three questions, “What is athlete doing wrong?”, “What should he be doing instead?”, and “What are the differences between these two ways?” Line drawings of erroneous and correct starts highlight the athlete’s problem and its tentative solution. Specifically, in an erroneous start, Jack jumped too high, entered the water too deep, glided too long (9 m), and experienced a difficulty with his first kick. In a correct start, the coach and athlete wanted a lower jump (take-off), a quicker and lower entering the
water, a shorter gliding distance (6-7 m), and a stronger first kick. They perceived the difference between erroneous and correct starts in the height of the jump, the angle of entering the water, gliding speed and distance, and the degree of difficulty-easiness of the first kick. Usually the error analysis, especially in educational setting, does not explicitly require establishing the causes of an error (for instance, in spelling or in concepts). Similarly, a teacher/coach suggests a correct movement pattern without a special consideration of how optimal it is for the individual's performance (matching an individual's resources).

**Error correction procedure**

As indicated earlier, error correction procedure involves four well-structured steps. During step 1, an athlete develops physical and mental awareness of erroneous movement (the old way). J did “jumping high – diving deep” starts and, as expected, first, he was physically unaware about his perceptions and bodily sensations that accompanied the erroneous movement. Transcripts of his self-reports indicate a gradual increase in his awareness. For instance, during his first start Jack noticed only that he “looked high up right before the jump”; his jump during the 5th start was high as usual and he thought about his ankles (“they are not flexible enough, thus my jump is high. I need to develop their flexibility”). By the 9th start J felt that “his arms were high during the flight, the flight was slow, entering water was deep, and it was difficult to start the first kick”.

Developing awareness of the new (correct) way during step 2 was successful and quick because the cause of the error was identified early enough. As a standard starting position did not match well this athlete’s physical build-up, it was suggested that he lowered the centre of gravity thus making it easier to jump in the right direction. The athlete began to clearly experience bodily sensations of starts performed in the new way with each start. For instance, during the 4th start (new way) he felt that “the push was strong now, the flight was longer, and the entry into the water was shallow”. Jack’s body was tense and he felt strong and ready to swim”. Spontaneously Jack wanted to compare the old and new ways of performing starts.

During the skill discrimination stage (step 3) the athlete contrasted the old (erroneous) and new (correct) ways by repeatedly performing and mediating this sequence of movements five times (starts 18 – 27). Calling the patterns old and new ways seemed to suit the athlete well. At this stage, Jack developed a clear sensation of difference between these starts: his starting position, the direction of jumps, hands movement, height of jumps, and entry into the water. Moreover, reporting these differences between erroneous and correct starts was now easy for the athlete. Observational data (start 24 “old way” and start 25 “new way” – concurs well with the athlete’s self-reports (Fig. 1a, b).

![Figure 1](image)

Finally, in practicing the new way (step 4), Jack performed six correct starts varying glance direction, gliding distances, the first kick and a pull. Despite accumulating tiredness, Jack did correct and strong starts with a long and strong pull. Jack also reported strong bodily sensations and a better and clear awareness of the new way. An overview of the entire session concluded the learning trial. All in all, Jack performed 34 starts during the 90-minute skill correction session (including warming up); all starts were done with a good speedy rhythm; the learning process succeeded well. During training, Jack’s self-confidence clearly developed and he was enthusiastic about his new start technique. He felt strong and wanted to swim immediately after a start, as the first kick was much stronger and more effective.

**A magnitude and stability of the LT-based change**

Prior to the LT, almost every second start was erroneous: Jack performed about 40% of correct starts in practices and about 50% of correct starts in competitions. An immediate post-LT follow up in two practices one day prior to the Nationals revealed 100% effectiveness of the change in start technique: all J’s eight starts were correct. In the Nationals, Jack did 11 correct starts (84.6%) from the total of 13 starts. Moreover, Jack was able to make a new start correctly in spite of the fact that starting blocks at this competition were too thick and it was difficult to get a normal grip (Table 1).
Table 1. Percentage of correct starts prior to and post-learning trial (LT)

<table>
<thead>
<tr>
<th>Time</th>
<th>Number of starts (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct</td>
<td>Incorrect</td>
</tr>
<tr>
<td>Prior to learning trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In practices</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>In competitions</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Post learning trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two practices (+2 days)</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Nationals (+ 3 days)</td>
<td>84.6</td>
<td>15.4</td>
</tr>
<tr>
<td>Four practices (+ 2 weeks)</td>
<td>83.3</td>
<td>16.7</td>
</tr>
<tr>
<td>WC (+ 4 weeks)</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Two practices (+ 8 months)</td>
<td>93.8</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Following the Nationals (the 3rd week post-LT), Jack did 24 starts during four practices and 20 starts (83.3%) were correct. Later in the 2001 World Championships all his 8 starts were correct (100%) and eight months following the LT, Jack did 15 correct starts (93.8%) from 16 starts. All in all, during this period, Jack did 62 (89.8%) correct starts from 69. In other words, the overall magnitude (83.3 -100%) and stability of change in start technique (immediately post LT, two weeks, and eight months later) were better than expected. The learning gains seem to have successfully transferred from practices to competition and the athlete’s self-reports (“now new starts are successful in about 90% of all cases”) support well observations of his coach.

Technique correction and performance

Three performance measures were used to examine whether the “new way” of starting would actually produce faster times. First, the results in the Nationals three days following the learning trial were quite impressive. Although with no tapering for this competition, both the coach and his athlete did not expect outstanding results, Jack improved two national records. Second, official starting times (15m) in competitions prior to and post-learning trial indicate an improvement in Jack’s performance. Specifically, prior to LT (old technique), his starting time at the 2000 European Championships was 5.96s. After LT (new start technique), Jack’s times in heats and in semi finals of the 2001 World Championships were 5.93s and 5.89s, respectively. The third performance measure in cluded regular check-ups in training three weeks prior to the major competitions. Swimming times in post-LT tests 3 weeks prior to major competitions were again better (4.8% improvement in Jack’s major event) than prior to learning trial (Table 2).

Therefore, the new starting movement suggested by the coach was superior to the old one. These findings indicate not only to a successful and permanent change in movement patterns following one LT but also to the improvement in swimming performance. Finally, Jack’s motivation and desire to swim with new feelings and kinaesthetic sensations also enhanced.

Table 2. Regular tests in practices 3 weeks prior to major competitions

<table>
<thead>
<tr>
<th>Testing situation</th>
<th>Jack’s swimming times (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st major event (25m)</td>
</tr>
<tr>
<td>Prior to learning trial</td>
<td></td>
</tr>
<tr>
<td>EC (Helsinki, 2000)</td>
<td>10.7</td>
</tr>
<tr>
<td>Olympics (Sydney, 2000)</td>
<td>10.3</td>
</tr>
<tr>
<td>Nationals (2001)</td>
<td>10.4</td>
</tr>
<tr>
<td>Post learning trial</td>
<td></td>
</tr>
<tr>
<td>WC (Fukuoka, 2001)</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Discussion and Applications

The aim of this case study was to determine whether old way/new way would be effective in skill correction with an Olympic athlete who experienced an established technique problem. Our findings indicate that an immediate and permanent change in start technique was achieved three days prior to the important competition, in which the swimmer also improved his performance. These results concur well with previous research effectively using the old way/new way in sport setting to correct learned errors and reduce the adaptation period to a new technique in skilled performance (12). However, it is important to realize that in the present case study, a change was achieved in a relatively short time prior to the important competition. These findings, therefore, extend earlier studies and interventions conducted off-season, during training, or several weeks prior to the major competition (12). Our results, therefore, provide additional empirical support for the notion that coping with proactive inhibition is crucial in rapid technique correction. Such a correction, in contrast to the conventional drill-based practice, is possible if an athlete first unlearns (forgets) quickly and permanently an erroneous (old) movement pattern and then shifts quickly to a new correct pattern. Therefore, this case study demonstrates the validity of the Lydon’s (14, 15) Old way/New way approach and its practical utility in bringing about an immediate and permanent change. It is important to realize however, that the core of the LT is not in merely increasing an athlete’s kinaesthetic awareness of erroneous (automatic) and correct way(s) of task execution (cf. 20). Rather, what matters most is the activation of mediation process contrasting old and new movement patterns that is crucial for overcoming PI.

The other important aspect of our case study is the positive impact of LT-based technique correction upon athletic performance. One should realize that the old way/new way does not claim that skill correction will always result in improvement of performance outcomes. Moreover, the method (14,15) initially developed in educational setting, focused mainly on the effectiveness (immediacy and...
permanency) of change in skill execution through coping with PI. Therefore, this framework predicts athletes' immediate response to change, their progress during the LT, and the permanency of change in subsequent performance. In high achievement sport, success of any intervention would be questionable if it did not result in improved performance outcomes. Thus the effectiveness of the intervention with our swimmer should be evaluated not only by immediacy and permanency of change in technique but also by the impact of this change upon performance. Our results show that this athlete's performance following the LT improved as well as his self-confidence and motivation.

Conceptually, the positive impact of change upon performance of our swimmer can be explained using the construct of "individually optimal performance". Specifically, according to the IZOFO model (10, 11, 12), individually optimal performance reflects the efficient use of an athlete's resources (strengths) with a possible compensation for the limitations (or a lack of certain resources). In contrast, a failure to use individual's resources and a focus rather on limitations than on one's strengths usually cause erroneous or inefficient performance. In our case, although an athlete's old way of start was similar to other swimmers', it was not based on his strengths and thus was less effective. On the contrary, the new way (correct start) was based on his strengths as well as compensated for within limitations in his body build. Therefore, the effective change in technique resulted in improved performance as a new movement pattern was individually optimal for this particular athlete.

The present case study made a special emphasis on identifying the athlete's individually optimal start technique. Therefore, the LT was successful in a rapid and permanent change in movement pattern and also in the improvement of performance outcomes. These data suggest that if a new technique (selected movement pattern) was not individually optimal for this athlete (11, 12), then the correction of error would result only in a rapid and permanent change in technique, but not necessarily in the improvement of performance. In other words, after a successful LT, an athlete can perform a new movement pattern, which may not always result in the improvement of performance outcomes. In such a case, PI is handled effectively, but the movement pattern is still ineffective.

Our results suggest a need for the extension of the old way/new way in sport setting involving error analysis and the selection of the new movement pattern. First, an error analysis should provide a detailed description of an error and its potential causes. Second, an erroneous performance should be conceptualised in terms of a mismatch between the athlete's resources (strengths and limitations) and task demands (11). Third, individually optimal technique should reflect the best match between the athlete's strengths and task demands and compensating for potential limitations in the athlete's resources. Finally, this new optimal movement pattern in some cases may be different from a generally accepted notion of the "best" technique.

Our case study focused on a practical solution of a disturbing technical problem in an Olympic level swimmer three days prior to the National championships. We are convinced that under such conditions our research design was most appropriate and practical in high-level sport setting. It is also important to realize that LT methodology is psychologically demanding (12) and therefore, we used only non-obtrusive measures (controlled observation and video/tape recordings) to avoid overloading the athlete. Thus, one limitation of this study was that we did not use individualized profiling (10, 11) to assess the athlete's emotion-motivational and cognitive-somatic components of performance-related state during execution of erroneous and correct starts. We also did not identify this athlete's individually optimal and dysfunctional patterns of psychobiological state as criteria to establish if he was (or was not) in the optimal zone during the entire LT.

Therefore, more research is clearly indicated to address these concerns and provide additional empirical support for the effectiveness of this new promising meta-cognitive strategy for the rapid and permanent correction of established technique difficulties experienced by highly skilled and less skilled swimmers. Finally, a special challenge for future researchers and practitioners in other sports is a rapid correction of learned errors under conditions of high physical risk and in sports with limited possibilities to repeat performance (e.g., ski-jumping, alpine skiing, diving).

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References


Peak Oxygen Uptake Responses to Free and Simulated Swimming Using Different Body Segments

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Abstract

Simulated swimming has been a useful tool in training and in assessment of physiological responses of swimmers. However, the extent to which oxygen uptake responses to simulated swimming compare to respective responses during free swimming is not yet known. The purpose of this study was to compare oxygen uptake responses in free and simulated swimming using different body segments. Five men (mean ± SD; mass: 67.2 ± 5.3 kg, stature: 1.74 ± 0.06 m, age: 19.1 ± 3.4 years) and four women (mass: 62.2 ± 3.1 kg, stature: 1.63 ± 0.04 m, age: 17.3 ± 4.1 years) club swimmers performed six incremental exercise tests to exhaustion. These tests comprised whole-stroke, arms-only and legs-only free and simulated swimming. Oxygen uptake (VO₂) was determined throughout the tests and at exhaustion (VO₂peak) using a portable telemetric system. VO₂peak during whole-stroke free swimming was 10.4 ± 2.0% higher than during simulated swimming (P<0.05), whereas VO₂peak during arms-only and legs-only free swimming did not differ from that of simulated swimming. These results suggest that oxygen uptake responses to arms-only and legs-only simulated swimming compare favourably with respective responses to free swimming, yet, there are still limitations to simulation of whole-stroke freestyle swimming in the laboratory.

Index Terms: Ergometry, swimmers, arms, legs.

Introduction

Difficulties in assessing physiological demands of swimming in the water have led to the development of laboratory-based ergometry. Arm-cranking has been used to assess arms-only peak oxygen uptake in sprint and middle-distance swimmers (Mericier et al. 1993). However, the majority of studies have used swim bench testing and have assessed: cardiopulmonary responses to exercise (Swaine and Zanker 1996); the effect of swimming training on arm VO₂peak of pre-pubertal girls (Obert et al. 1996) and acute responses to interval exercise (Sexsmith et al. 1992). The relationship between arm VO₂peak responses to laboratory- and water-based testing has been investigated in only one study (Ogita and Taniguchi 1995). To our knowledge there are no published comparisons of whole-stroke or legs-only VO₂peak responses to free and simulated swimming.

Similarly, there have been few studies of VO₂peak responses to lower-body exercise in swimmers. Those that have occurred have used free (Adriu et al. 1966) and flume swimming (Ogita et al. 1996) and have focused on the freestyle leg-kicking action. Determinations of VO₂peak responses to freestyle leg-kicking exercise using laboratory-based ergometry have been hindered by the absence of a suitable ergometer. Recently, a simple device has been used to assess VO₂peak re-
sponses to freestyle leg-kicking (Konstantaki and Swaine 1999). However, the extent to which these responses to ergometric leg-kicking exercise reflect similar measurements performed during free swimming has not yet been investigated.

By comparison, oxygen uptake responses to whole-stroke swimming (\( \text{VO}_2 \text{peak} \)) have been explored extensively using water-based methods. These studies have included: the mechanical efficiency of front crawl swimming (Toussaint et al. 1990); a comparison of maximal oxygen uptake during tethered and free swimming (Reinhardt et al. 1991); and the relationship between oxygen uptake, stroke rate and swimming speed in competitive swimming (Wakayoshi et al. 1995). However, there have not been any investigations into \( \text{VO}_2 \text{peak} \) responses to whole-stroke simulated swimming, because there has not been an ergometer which allows swimmers to replicate the whole-stroke freestyle swimming action in the laboratory. In an attempt to meet this shortcoming, a combined arm-leg ergometer, that incorporates the use of an interfaced swim bench and a leg-kicking machine, has been developed (Swain et al. 1998).

This type of ergometer offers improved opportunities for studying swimming and swimmers. As it allows quantification of arm and leg power output, it is possible to compare physiological responses to swimming movements involving different body segments, at the same absolute exercise intensities. Such assessment has not been possible and would be useful in monitoring the changes in arm and leg power output of swimmers, which might have implications for the effectiveness of a swimming training program. Also, this ergometer offers the opportunity for simultaneous measurement of the quantity of external work performed by the upper and lower body segments during whole-stroke exercise. Similarly, this has not been possible previously. Such assessment would be useful in quantifying the contribution of the arms and legs to whole body physiology of swimmers. The purpose of this study was to compare oxygen uptake responses to whole-stroke, arms-only and legs-only free and simulated swimming.

Methodology

Participants

Five men (mean ± SD; body mass: 67.2 ± 5.3 kg, stature: 1.74 ± 0.06 m, age: 19.1 ± 3.4 years) and four women competitive swimmers (mean ± SD; body mass: 62.2 ± 3.1 kg, stature: 1.63 ± 0.04 m, age: 17.3 ± 4.1 years) were recruited from the 'Bedford Modernians' Swimming Club. All swimmers provided written informed consent prior to participation in the study. For the three months prior to the study they performed a mean of 4.5 training sessions per week. Their mean weekly training distance was 16000 ± 3000 m. All participants performed three swimming tests: a whole-stroke, an arms-only and a legs-only freestyle swimming test. Each test was performed in a 23-metre swimming pool on a separate day. The participants also performed three simulated swimming tests: a whole-stroke, an arm-pulling and a leg-kicking test. Each of these tests was performed in the laboratory on a separate occasion. The order of the tests was randomised to eliminate possible learning effects. Participants were allowed to familiarise with test procedures by practice in the laboratory and the swimming pool on two separate occasions. This study received ethics approval from the North Bedfordshire Ethics Committee in the United Kingdom.

Equipment

Arm-pulling and leg-kicking ergometers

The laboratory-based simulated swimming tests used a computer-interfaced swim bench (arm-pulling ergometer; H. and M. Engineering, Gwent, Wales, UK) and a leg-kicking machine (University of Warwick, Warwick, UK). The arm-pulling ergometer is an adapted version of a biokinetic swim bench, which incorporates a transducer, an interfaced microprocessor and a resistance unit. The calibration of the arm-pulling ergometer has been described previously (Swain and Zanker 1996), but briefly consists of timing the vertical drop to the ground of different weights that are attached to each hand paddle of the ergometer. The leg-kicking machine is an adaptation of the swim bench and briefly comprises a platform on which two alloy wheels are fixed on a vertical arrangement. These alloy wheels are connected with non-stretch rope, which runs around them. The rope is interrupted by placement of two stirrups (one on either side of the rope) into which the swimmer can place his/her feet to simulate the free style leg-kicking movement while lying prone on a bench. The leg-kicking ergometer is connected to the arm-pulling ergometer's resistance and transducer units. Similarly, this ergometer has been described previously (Konstantaki and Swaine, 1999).

Whole-stroke simulated swimming ergometer

The whole-stroke simulated swimming ergometer incorporates the use of the arm-pulling and leg-kicking ergometers (Swain et al. 1998). A purpose-built swing frame with a suspended platform was specially designed to support the upper body and hips of the swimmer and was held approximately 1 m from the ground. The arm-pulling and leg-kicking ergometers are arranged in front of and behind the platform, respectively. The distance at which these two ergometers are placed in relation to the platform depends on the stature of the swimmer and is adjusted accordingly. Swimmers adopted a prone position on the suspended platform and placed their hands in the hand paddles attached to the arm-pulling ergometer, while placing their feet in the stirrups on the leg-kicking ergometer (Plate 1). To achieve comfort on the
platform and allow full range of motion, the swimmers' legs and arms were slightly flexed, at rest. To replicate the front crawl swimming action, the swimmers pulled backwards on the hand paddles with alternating arms, whilst kicking upwards and downwards with alternating legs.

**Gas analysis equipment**

Gas analysis equipment used a portable system (COSMED K2, Rome, Italy) to allow measurements of oxygen uptake throughout all tests. This system comprised a transmitter and a receiver unit operating on rechargeable batteries. COSMED K2 has been shown to be a valid and reliable instrument for measurements of oxygen uptake \( \text{VO}_2 \) when compared to respective measurements obtained by a metabolic measurement cart (Peel and Utsey 1993) and by the Douglas bag method (Lucia et al. 1994). More recently, the validity and reliability of COSMED K4b2 (an updated version of K2) measurements of VE (minute ventilation), oxygen uptake \( \text{VO}_2 \) and carbon dioxide output \( \text{VCO}_2 \) were shown to be within the limits of agreement (mean difference \( \pm \)2 SD) as determined by the Bland-Altman technique - when compared to respective measurements obtained by a metabolic measurement cart (Duffield et al. 2004).

COSMED K2 was calibrated prior to and verified after each testing session. Calibration consisted of flushing the mixing chamber with atmospheric air. This resulted in the activation of the sampling pump so that the %O\(_2\) value coincided with the expected value (i.e. 20.9%). Measurements of CO\(_2\) production were not possible, as this system does not have a CO\(_2\) sensor. Rather, expired gases were passed through an O\(_2\) sensor, which detected the oxygen concentration in the expired air and logged the data in analogue values. The data were then transmitted to the receiver unit (equipped with an analogue-to-digital converter) and expressed as numerical values. The receiver unit was set to record gas exchange readings and compute mean oxygen uptake over 5 s intervals.

**Free Swimming Tests**

**Development of instrumentation to measure \( \text{VO}_2 \) in the water**

A waterproof mouthpiece was designed for use with the COSMED K2 portable gas analysis system (Plate 2). This used a two-way (T-shape) non-rebreathing valve (Hans Rudolf, Series 2700). The inhalation and exhalation ports of this valve were each connected to a breathing tube. The connection points were shielded with waterproof adhesive tape. The other end of each breathing tube was connected to the turbine of the COSMED K2 analyser. The mouthpiece was secured onto the swimmers' head using suitable headgear.

**Development of exercise protocols**

The swimming tests comprised arms-only, legs-only and full-stroke freestyle. To determine appropriate starting speeds and duration for each of these tests, the swimmers performed time trials on three occasions. On the first occasion, swimmers were instructed to complete two lengths of a 23-metre pool using arms-only (the legs were supported by a pull-buoy) freestyle swimming. The swimmers were instructed to swim the first length at their slowest time, rest for 1 minute and then, swim the second length at maximum effort. On the second and third occasions, the swimmers completed a 'slow' and a 'fast' length using legs-only (with a kick board) and full-stroke freestyle swimming, respectively. The times for the 'slow' and 'fast' lengths for each time trial were recorded for every swimmer. The mean time to complete a 'slow' length was used as starting speed, whereas the mean time to
complete a ‘fast’ length was used to determine the duration of each swimming test. All tests used incremental exercise protocols, which were specially designed (De Montfort University Bedford, UK) to elicit peak oxygen uptake and peak heart rate responses within 10 minutes of arms-only, legs-only and full-stroke freestyle swimming, respectively. These exercise protocols used a series of audio signals recorded on a tape (Tandberg Audio Tutor TAN771). Signals were generated using a two-channel process timer (Electronic Developments, Hampton, Middlesex, UK), linked to a tone generator. An 80 W speaker connected to a tape recorder delivered the audio signals. A triple audio signal marked the start of each test. Swimmers were instructed to swim to the end of the 23-metre swimming pool, then turn around (without tumble turning) and wait for the audio signal to sound before starting to swim back. The speed for each length was set to increase in small increments (i.e. 1 second per 92 metres) until the swimmers reached exhaustion.

Free swimming tests

For the arms-only test, swimmers used the arms-only freestyle swimming action (Plate 3). A pull-buoy supported the swimmers’ legs during this test, whereas an elastic band was placed around the ankles to prevent any leg-kicking action. Swimmers were instructed to complete the first length of the 23-metre pool in 28 seconds. Thereafter, completion time for each subsequent length was set to decrease by 0.25 seconds (i.e. signals sounded at 0.25 second lesser intervals for every length). For the legs-only test, swimmers were asked to perform the freestyle leg-kicking action. To maintain a low resistance posture in the water and support the upper-body, subjects used a kick board. Swimmers had to complete the first length of the 23-metre pool in 32 seconds. Thereafter, completion time for each subsequent length was set to decrease by 0.25 seconds. For the full-stroke swimming test, swimmers used freestyle swimming. Completion time for the first length was 26 seconds. Thereafter, completion time for each subsequent length was set to decrease by 0.25 seconds. The free swimming tests ended at volitional exhaustion. Oxygen uptake (VO₂) and heart rate (HR) were continuously recorded throughout the tests at 5-second intervals and at exhaustion (VO₂peak; HRpeak).

Simulated swimming tests

Arm-pulling and leg-kicking tests

All swimmers performed two ramp-type incremental exercise tests to exhaustion using the arm-pulling and leg-kicking ergometers. For arm-pulling, exercise intensity was dictated by a computer programme and was set to increase by 7.5 W·min⁻¹ with a starting power output of 20 W. This exercise protocol has been shown to elicit fatigue within 10-15 minutes during arm-pulling (Konstantaki and Swaine 1999). Maximal pull velocity (MPV) was set constant at 2.66 m·s⁻¹ and at 2.74 m·s⁻¹ to allow optimal stroke rates at higher and lower resistance for men and women, respectively (Swaine and Zanker 1996). For leg-kicking, the leg-kicking machine was connected to the resistance unit of the arm-pulling ergometer. Exercise intensity was dictated in the same way as for arm-pulling. MPV was set constant at 2.74 m·s⁻¹ for men and 2.80 m·s⁻¹ women, respectively. Pilot testing identified these settings as appropriate to elicit fatigue within 10 minutes during leg-kicking. The duration of the arm-pulling and leg-kicking tests was selected so as to mirror the duration of the arms-only and legs-only free swimming tests.

Whole-stroke simulated swimming test

Swimmers were asked to replicate the freestyle swimming action by pulling and kicking in a synchronised action and were encouraged to body roll. For arm-pulling, exercise intensity was dictated in the same way as for the individual arm-pulling test. Also, the same MPV settings were used for male and female swimmers as described previously. The resistance unit of a second swim bench (Model 26E, Fitness Systems Inc., Missouri, USA) was used to provide resistance to leg-kicking. The pulleys of this swim bench were connected to hooks on the bottom of each stirrup on the leg-kicking machine. The ‘medium’ and ‘low’ resistance settings were used on the swim bench for men and women swimmers, respectively. These resistance settings were similar to the resistance settings used during the individual leg-kicking test (i.e. 2.74 m·s⁻¹ for men and 2.80 m·s⁻¹ for women). Swimmers were instructed to increase the length and/or rate of their kicking action every time the intensity increased during the arm-pulling test (dictated by the computer programme). The
test progressed until maximum effort was achieved and was terminated at exhaustion.

**STATISTICAL ANALYSIS**

After verifying underlying assumptions, a two-way analysis of variance (ANOVA) with repeated measures on two factors (swimming versus simulated swimming and mode of testing) compared VO\textsubscript{2peak} and HR\textsubscript{peak} in simulated and free swimming. Significance was set at $P<0.05$. The relationship between heart rate and oxygen uptake responses to arms-only, legs-only and whole-stroke exercise was also explored using Pearson’s product moment correlation coefficient. Values are reported as mean ± SD.

**RESULTS**

VO\textsubscript{2peak} responses to full-stroke freestyle swimming were (mean ± SD) $10.4 ± 2.0\%$ higher than VO\textsubscript{2peak} responses to whole-stroke simulated swimming ($4.12 ± 0.4$ L·min\(^{-1}\) versus $3.69 ± 0.2$ L·min\(^{-1}\); $P<0.05$). VO\textsubscript{2peak} responses to arms-only and legs-only freestyle swimming ($3.36 ± 0.3$ L·min\(^{-1}\) and $3.55 ± 0.4$ L·min\(^{-1}\), respectively) did not differ from respective responses to arms-only and legs-only simulated swimming ($3.22 ± 0.4$ L·min\(^{-1}\) and $3.15 ± 0.5$ L·min\(^{-1}\), respectively) at $P>0.05$. These results are shown in Figure 1. VO\textsubscript{2peak} responses to whole-stroke freestyle swimming were higher than VO\textsubscript{2peak} responses to arms-only and legs-only swimming by $18.2 ± 3.0\%$ and $14.4 ± 2.1\%$, respectively ($P<0.05$). Also, VO\textsubscript{2peak} responses to whole-stroke simulated swimming were higher than VO\textsubscript{2peak} responses to arms-only and legs-only simulated swimming by $13.6 ± 4.3\%$ and $15.5 ± 2.5\%$, respectively ($P<0.05$).

**DISCUSSION**

The purpose of this study was to compare oxygen uptake responses to whole-stroke, arms-only and legs-only free and simulated swimming. It was shown that whole-body VO\textsubscript{2peak} was higher in free compared to simulated swimming. This finding suggests that the whole-body aerobic potential of swimmers could be underestimated in the laboratory using the whole-body simulated swimming ergometer. However, this difference is probably due to limitations inherent in the use of the whole-body simulated swimming ergometer. The current design of this ergometer allows limited body roll, whereas the prone position of the swimmer on the platform causes chest compression, which has been documented to limit ventilation at high intensities of exercise (Swaine and Reilly 1983). Another design limitation is that it is not possible to perform over-arm recovery or simulate the six-beat leg-kick at high intensities of exercise. Other limitations could have included the immersion-induced bradycardia (Holmér 1979) and the disruption to the breathing pattern due to the use of a mouthpiece. In this study, these limitations were not accounted for when using the whole-body simulated swimming ergometer.

Whole-body VO\textsubscript{2peak} was higher than arms-only or legs-only VO\textsubscript{2peak} in free swimming. In this study, similar differences were observed in simulated swimming, where whole-body VO\textsubscript{2peak} was higher than arms-only or legs-only VO\textsubscript{2peak}. These findings agree with those of previous studies that have assessed whole-body peak oxygen uptake using water-based ergometry, such as the swimming flume (Ogita et al. 1996). Also, it has been previously demonstrated in studies that have used cycling ergometry that a greater aerobic demand is placed on the body during whole-body exercise compared to arms-only or legs-only exercise (Currie et al. 1992). This response has been attributed to involvement of greater muscle mass during whole-body exercise (Hoffman et al. 1996).

There was no difference between arms-only and legs-only VO\textsubscript{2peak} in free and simulated swimming. This finding contradicts those of previous studies where the highest oxygen uptake achieved during exercise with the legs is generally 20-30% higher than during arm exercise (Sawka 1986). These differences have been attributed to the relatively smaller muscle mass of the upper-body used in arm ergometry compared to the muscle mass of the legs used in cycling ergometry (Miles et al. 1989). Nevertheless, these studies used arm-cranking and cycling ergometry and did not use swimmers. The findings of our study suggest that, in swimmers, the aerobic conditioning of the arms could be similar to that of the legs, which is probably an adaptation to competitive swimming training (Strømme et al. 1977). It appears that the ergometry used in our study successfully engages the major muscle groups required by free swimming and provides
an improved reflection of the aerobic potential of the arms and legs of swimmers over other ergometric methods.

Finally, the design limitations of the whole-body simulated swimming ergometer need to be addressed to allow reliable assessments of the whole-body aerobic potential of swimmers in the laboratory. Such assessments might be useful in investigations of the relative contribution of the arms and the legs to the physiological responses to swimming. In particular, the contribution of the freestyle leg-kicking action to the overall physiological response to swimming has been de-emphasised and largely overlooked.

APPLICATIONS

The findings of this study demonstrate that simulated swimming might be a useful tool in assessment of the aerobic potential of the arms and legs of swimmers. It was shown in this study that peak oxygen uptake responses to simulated arm-pulling and leg-kicking compared well with respective responses to arms-only and legs-only free swimming. The major advantage that simulated swimming assessments offer is that responses can be related to exercise intensity. Coaches may use such assessments to monitor the changes in arm and leg aerobic capacity of their swimmers at given exercise intensities during the different phases of periodisation. This approach may have useful implications for assessing the effectiveness of swimming training regimes and also for monitoring the increases in arm or leg power output when rehabilitating injured swimmers.

Another useful application of this type of simulated swimming assessments offer is the possibility to compare the aerobic capacity of the arms versus the legs at the same given exercise intensities in elite and less-proficient swimmers. Such assessment would be useful in identifying possible stages of swimming progression as reflected by increases in power output. Surely, similar assessments can be made using the swimming flume, but these assessments can only be related to swimming velocity. It is our view that exercise intensity is more easily quantifiable than swimming velocity in regards to planning and evaluating swimming training programmes. Therefore, coaches may use this novel type of ergometry to assess the aerobic potential of the arms and legs of their swimmers in relation to power output. There are still some limitations inherent in the use of the whole-body simulated swimming ergometer, but once these are addressed more assessment possibilities could arise, such as assessing the contribution of arms and legs to the whole-body aerobic potential of swimmers.

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REFERENCES


Using Cardiopulmonary Functions to Determine the Effectiveness of a Taper

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Abstract

A group of 13 male competitive swimmers ranging in age from 18 to 22 participated in a study examining the effectiveness of a training taper. After a five-week training program, a ten-day taper was implemented. Each participant performed a pre- and post-taper exercise test on a Medical Graphics treadmill with a modified ramp protocol. Various cardiopulmonary function (CPF) values were recorded. Oxygen consumption per pulse per kilogram (VO₂/HR/kg) at anaerobic threshold (AT) was found to be a significant (P<0.003; r=-0.389) overall predictor of efficacy of the taper. Using improvement ratios, which ranged from −1.7 to 6.1 s/100yd between the pre-taper and post-taper values (with a mean of 1.54 s/100yd), the group was divided into two subsets—those falling above and below the mean. CPF values were used to analyze the extent to which they reflect levels of athletic performance. A t-test analysis for the two subsets displayed a number of significant values at anaerobic threshold: VO₂: P<0.007; VO₂/HR: P<0.001, VO₂/kg: P<0.006, and VO₂/HR/kg: P<0.002, and at maximal oxygen consumption (VO₂ max): VO₂: P<0.014, VO₂/kg: P<0.016. Mean increase or decrease of VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg values for the individual subsets indicates that the taper was effective for those whose performance improved above the mean of 1.54 s/100yd, and not as effective for those whose improvement ratio fell below the mean (i.e., the taper may not have been adequate for recovery from the preceding training regimen). Because this suggests that the level of increase or decrease of certain individual CPF values may be used to estimate the efficacy of a taper, it supports the use of a mid-season taper as an opportunity to determine the individual athlete’s recovery profile for application to the end-of-season taper.

Index Terms: Fatigue, VO₂ max, anaerobic threshold, oxygen consumption

Introduction

The purpose of this investigation was to provide swimming coaches with a generalized profile, or group of indices, based on physiological measurements through which they will be able to monitor the efficacy of a taper. The goal of the taper in a competitive swimming program is to allow adequate time for recovery from the fatigue associated with the training regimen. The desired result is maximal swim performance at a specifically designated time. Most current research available to swim coaches focuses on world-class athletes. While this has significant application to the Olympic movement and NCAA Division I athletes and programs, it may not always be applicable to the remainder of the athlete pool, such as athletes competing in NCAA Divisions II and III. Due to the increasing level of competition involved in the current NCAA championship qualification process and, in particular, the provisional qualifying system, coaches are continually seeking ways to enhance the success of their training programs.

Rest and decreases in daily training distances are associated with taper and normally result in performance improvements. The extent of the rest and the duration of the taper is individually based upon each athlete’s need. An increased
number of coaches are utilizing a mid-season taper as a means to acquire valuable information from a physiological perspective about their athletes. This information can then be optimally applied to the final taper at the end of the season.

Studies of fatigue reveal that several factors (including various hormone levels, blood cell concentrations and components, and products of metabolism) may vary with the state of fatigue. Additionally, individuals respond differently to exercise-induced fatigue. While these indices may be beneficial in assessing fatigue, few are reliable. Levels of adrenocorticotropic hormone increase with acute fatigue (2), but decrease with chronic fatigue (19). Growth hormone levels decrease with chronic fatigue (19) but remain unchanged with acute fatigue (2). White blood cells do not consistently change with acute or chronic fatigue (3, 8, 10, 12, 13). Other factors such as lactic acid metabolism and chromium levels have been utilized to measure fatigue with mixed success (1, 13, 18). Concerns exist regarding the common practice, availability, expense and ease of use of these indicators of fatigue for the majority of swimming programs. Therefore, other readily obtainable and reliable indices determining the state of fatigue and methodologies need to be explored and evaluated.

Maximal oxygen consumption (VO₂ max) is a common indicator of exercise tolerance (4). VO₂ max is defined as the highest one-minute value of oxygen uptake (i.e., less than 150 ml variance) during a workload of progressing intensity (11). Studies have shown that an age-associated decline in levels of VO₂ max results from a decrease in maximum heart rate, stroke volume, skeletal muscle mass and an increase in adiposity (6, 7, 16). The decrease in VO₂ max corresponds with a reduction in work capacity and, therefore, a decline in exercise capacity. This suggests that an increased VO₂ max would indicate a greater exercise capacity. Research over the past twenty years has shown that endurance training can inhibit some age-related declines in the measures of physical fitness, such as VO₂ max (5, 9). Evidence suggests that limitation of cardiac output is the main cause for the decline in VO₂ max (15), and can therefore contribute to a corresponding decrease in physical endurance.

Physical fitness can be measured from physiological factors by examining the interdependence between the heart and lungs. These cardiopulmonary function values, including oxygen consumption (VO₂), respiratory exchange ratio (RER), oxygen consumption per heart rate (VO₂/HR), oxygen consumption per heart rate per kilogram body weight (VO₂/HR/kg), and end tidal pressure of oxygen (PETO₂) can be obtained at both VO₂ max and the anaerobic threshold (AT). Anaerobic threshold is defined as the coinciding occurrence of the minimum value of the oxygen coefficient (V₀₂/VO₂) and the minimal PETO₂, the temporarily constant value of the carbon dioxide coefficient (V₀₂/VO₂), and the systematically increasing value of the RER (VO₂/VO₂) and PETO₂ from their observed minimums (11). Utilizing these cardiopulmonary function values as the basis, the design and practical application of this investigation was to develop a reliable and readily obtainable profile for evaluating the efficacy of a taper.

While a swim flume presents a more analogous picture of the physiological parameters associated with swimming than does a treadmill, most Division III coaches do not have readily available access to a flume. Access to a treadmill may be limited as well, but many local hospitals or rehabilitation facilities have CPX-D (cardiopulmonary exchange device) and treadmills and are more accessible than flumes. Studies have shown that the differences in testing of competitive swimmers with a flume, a treadmill, or a bicycle are minimal or insignificant, particularly at maximum exercise (17).

Though conducting stress tests through the utilization of the CPX-D and treadmill generates data useful in evaluating a subject’s fitness, anaerobic threshold and gas exchange, the relevance in this study focuses primarily on the aspect of the onset of fatigue as it relates to the taper. Determining the onset of fatigue during the stress tests can provide useful information about the subject’s fitness and has particularly important relations when considering the taper.

Given the number of different parameters and indices involved with fatigue, the study was not conducted with the hope of establishing a robust find or single determinant of fatigue, rather consideration for a few accessible values such as RER, PETO₂, VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg by which a physiological profile of the subject’s condition could be constructed. While RER and PETO₂ values may correlate with the level of fitness, there are a host of other uncontrollable variables that influence them and may be difficult to determine as a robust find. Other values such as VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg are equally important in determining the improved fitness and efficacy of the taper.

The question arises regarding the possible relationship of improved athletic performance and cardiopulmonary function values. Consideration should also be given to the significant differences in values such as RER, PETO₂, VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg at AT and VO₂ max as they correspond with the subject’s level of fitness.

Methodology

Screening: A group of 13 male competitive swimmers ranging in age from 18 to 22 were asked to participate in a study examining training and taper. A physician or physician assistant interviewed and examined each volunteer to determine acceptability and possible health risk. The clinical evaluation included a medical history and physical exam consisting of, but not limited to, monitoring of 12-Lead ECG while resting, measurement of blood pressure and heart rate, and auscultation of chest sounds and peripheral pulses. Each participant signed a written informed consent statement. As members of the collegiate team, each swimmer had previously
undergone the institutional pre-participation physical examination.

**Training:** During the five weeks preceding the taper, the training program was divided into two different segments. The first segment consisted of a two-week training regimen in which the athletes swam between 10,000 and 12,000 yards per day divided into two 120-minute training sessions. The second segment, weeks three through five, consisted of a regimen in which the athletes swam between 5,800 and 7,200 yards per day in a single 120-minute session. (This training pattern is based on the availability of training opportunities for the team after the holiday/exam break, prior to the beginning of the new semester in the second half of the collegiate season.)

**Pre-Taper Testing:** Each athlete performed an exercise test one day before the taper on a Medical Graphics treadmill with a modified ramp protocol (20). During the exercise testing, a Medical Graphics Pulmonary Stress System (CPX-D), offered breath-by-breath analysis of oxygen consumption and carbon dioxide output. The technician also used a Marquette 12-lead ECG. The participants performed the progressive exercise test with gradually increasing effort until they reached the point of exhaustion.

**Taper:** After a five-week training program, a ten-day taper was implemented. The taper consisted of incrementally decreasing yardage and increasing rest (i.e., from 5,200 to 2,000 yards in a single session of 60 to 90 minutes).

**Post-Taper Testing:** An identical testing protocol was used after the taper as before the taper.

**Performance Measure:** The athlete's best non-tapered swimming performance in his primary event through the course of the season was compared with his tapered performance. Events ranged from 50 yards to 1650 yards of various strokes. The data were presented as average time change per 100 yards to be able to compare divergent events on a common index. The actual events are presented in Table 1.

### Table 1. Best non-tapered swimming performance compared with tapered swimming performance.

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Event</th>
<th>Improvement Ratio (s/100yds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200 yd IM</td>
<td>6.1</td>
</tr>
<tr>
<td>2</td>
<td>200 yd breaststroke</td>
<td>5.4</td>
</tr>
<tr>
<td>3</td>
<td>1650 yd freestyle</td>
<td>3.2</td>
</tr>
<tr>
<td>4</td>
<td>1000 yd freestyle</td>
<td>2.6</td>
</tr>
<tr>
<td>5</td>
<td>400 yd IM</td>
<td>2.4</td>
</tr>
<tr>
<td>6</td>
<td>200 yd breaststroke</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>100 yd backstroke</td>
<td>2.1</td>
</tr>
<tr>
<td>8</td>
<td>100 yd butterfly</td>
<td>1.4</td>
</tr>
<tr>
<td>9</td>
<td>200 yd freestyle</td>
<td>0.8</td>
</tr>
<tr>
<td>10</td>
<td>50 yd freestyle</td>
<td>0.7</td>
</tr>
<tr>
<td>11</td>
<td>200 yd. backstroke</td>
<td>-0.1</td>
</tr>
<tr>
<td>12</td>
<td>100 butterfly</td>
<td>-0.6</td>
</tr>
<tr>
<td>13</td>
<td>500 freestyle</td>
<td>-1.7</td>
</tr>
</tbody>
</table>

### Statistical Analysis:
Both a multiple regression and a t-test analysis were performed using the Statistics Package for the Social Sciences (SPSS) software to determine the significance of the cardiopulmonary function values measured. The percent change in the cardiopulmonary function values between pre- and post-taper testing were calculated from the recorded data and used in the determination of significance. A stepwise multiple regression was used to determine those cardiopulmonary function values which were the most useful predictors of the desired results (i.e., those values whose change indicates that the taper was beneficial). A total of 95% confidence or above). This statistical method was selected because it is appropriate for determining how those swimmers who benefited most from the taper differ physiologically from those who benefited least.

A two-tailed t-test analysis helped to determine the significance of the individual subsets—those above and below the mean of the entire group (i.e., 1.54 seconds improvement ratio)—as they correlate with the improvement ratio.

### Results
The results of this investigation are presented in Tables 2-4.

### Table 2. Improvement ratios and cardiopulmonary function values with 5% change of subset 1 (>1.5 improvement ratio)

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Performance Test</th>
<th>Improvement Ratio</th>
<th>% Change</th>
<th>Improvement Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pre-Taper</td>
<td>2.2</td>
<td>-0.1</td>
<td>2.1</td>
</tr>
<tr>
<td>2</td>
<td>Post-Taper</td>
<td>1.4</td>
<td>-0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>Pre-Taper</td>
<td>2.6</td>
<td>-0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>Post-Taper</td>
<td>2.2</td>
<td>-0.8</td>
<td>1.1</td>
</tr>
</tbody>
</table>
are presented. Table 3 summarizes the results of the statistical analyses.

Using a stepwise regression statistical method for percent changes (post- minus pre-taper results), VO₂/HR/kg at AT was found to be a significant predictor ($P<0.003; r=-0.389$) for improvement ratio, explaining 15.2% of the variance. No other cardiopulmonary function values were found to be a significant predictor of improvement ratio.

The t-tests for the two subsets displayed a number of significant values at AT (VO₂: $P<0.007$, VO₂/HR: $P<0.001$, VO₂/kg: $P<0.006$, and VO₂/HR/kg: $P<0.002$) and VO₂ max (VO₂: $P<0.014$, VO₂/kg: $P<0.016$) as shown in Table 3. There were no significant differences found for $P_{O_2}$ and RER at AT, or VO₂ max, VO₂/HR and VO₂/HR/kg at VO₂ max.

**Discussion**

The significance in the changes associated with cardiopulmonary function values (Table 1 and 2) of the entire group of swimmers (N=13) was analyzed using a stepwise regression statistical method. The percent change of VO₂/HR/kg at AT values from pre- and post-testing was found to be a significant predictor ($P<0.003; r=-0.389$) of improvement ratio. The improvement ratio for an athlete is expected to increase when the percent change of VO₂/HR/kg at AT value is found to decrease. Because the taper explains 15.2% of the variance in improvement ratio, we can infer that an adequate taper would contribute to improved athletic performance while an insufficient taper would hinder athletic performance. This is consistent with the experience of most swimming coaches.

After consideration of the groups' values as a whole, a review of the individual swimming performances revealed a spread from −1.7 to 6.1 seconds per 100-yard improvement ratio between the pre-taper and post-taper values with a mean of 1.54 s/100yd. The group was then divided into two subsets, greater than or less than the mean improvement ratio. A two-tailed t-test analysis determined differences in the means of the individual subsets.

The t-tests for the two subsets displayed a number of significant values at AT (VO₂: $P<0.007$, VO₂/HR: $P<0.001$, VO₂/kg: $P<0.006$, and VO₂/HR/kg: $P<0.002$) and VO₂ max (VO₂: $P<0.014$, VO₂/kg: $P<0.016$) as shown in Table 3. The improvement or increase in VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg values for subset one indicate that the taper was effective, that is it provided adequate rest and recovery from the preceding five-week training routine. The decrease in VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg values for subset two indicate that the taper was not as effective (i.e., the incrementally decreasing yardage did not provide adequate recovery from the preceding five-week training routine). For two other values, RER and $P_{O_2}$, no significance was found and thus no correlation was indicated for the efficacy of the taper.
Applications

This investigation supports the use of a mid-season taper as an opportunity to determine the individual athlete’s recovery profile (i.e., cardiopulmonary function values) for application in the end-of-season taper. In other words, by taking the athlete’s response and cardiopulmonary function values to the mid-season taper, the swimming coach may make the necessary adjustments to allow for adequate time for recovery from exercise-induced fatigue associated with the training regimen.

After consideration of the groups’ swimming performance, individuals were assigned into one of the two main subsets—those with an improvement ratio above and below the mean of 1.54 s/100 yds. The individuals in subset 1 showed an increase in VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg values at AT and VO₂ max. The individuals in subset 2 showed a decrease in these same values. The individual demonstrating a greater improvement ratio developed an increase in oxygen uptake and oxygen pulse (VO₂/HR) for his body weight both in an aerobic and anaerobic level of exercise. The improved values may indicate a delay in the onset of anaerobic threshold and thus the individual’s maintenance of a primarily aerobic state for longer periods of time.

After completing the training regimen, the swimming coach is looking for easily obtainable characteristics to determine the amount of rest the athlete requires. Inherent in the design of a successful taper, the swimming coach is continually considering the amount of time or duration of the taper to maximize the effect. The measurement of cardiopulmonary function values and their evaluation may assist the swimming coach in determining sturdier generalizations (i.e., a profile) for assessing the individual’s potential for maximum performance.

When constructing a profile for an individual swimmer, the coach can utilize the information established from the cardiopulmonary function values obtained at the mid-season taper to determine the amount of rest required for each athlete with an increased level of confidence. The positive reinforcement of improved cardiopulmonary function values has inherent potential for improving the intrinsic motivation of the individual athlete. The cardiopulmonary function values considered in constructing a profile include VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg values at both anaerobic threshold and VO₂ max. The combination of certain, but not necessarily all, values will assist the coach in being able to design a specific profile for the sprinter, middle distance, and long distance swimmer. Improved cardiopulmonary function values, may indicate an improved level of performance.

Though significance was not demonstrated in this small sample size for P<sub>T</sub>VO₂ and RER, significance may be demonstrated in a larger sample size. Further study should be instrumental in determining which cardiopulmonary function values are more important in predicting maximum performance and better suited for identifying an accurate profile. In reviewing these findings, it is important to note that there were certain variables that were outside the control of this particular experiment. For example, diet and sleep schedule were not held constant in the study.

Significant findings would suggest that profiles could be utilized to group athletes in terms of their cardiopulmonary function values in response to exercise-induced fatigue. These profiles can be utilized by swimming coaches to design a more effective taper for a greater percentage of their athletes and thus improve the overall success of their swimming program.

The availability of individual VO₂, VO₂/HR, VO₂/kg, and VO₂/HR/kg values may be used to predict the efficacy of a taper as a determination whether athletes have or have not reached their maximal performance at the specifically designated time. Coaches can use the cardiopulmonary function evaluation to assess the physiological measurements that have been highlighted in this study as significant for each of their athletes. Given the number of athletes in a swimming program, it is often impractical to design the taper to meet each athlete’s physiological need and thus, it may be more pragmatic to group athletes with similar values.

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Prediction of Performance Using Physiological and Stroke Variables in a Sample of Adult Competitive Swimmers

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Abstract

Purpose: The purpose of the present investigation was to develop a correlational model that describes physiological and stroke factors which explain 50 and 500 yard freestyle swimming performance times in adult male and female competitive swimmers. Methods: Sixteen male and twelve female competitive swimmers between 19 and 40 years of age participated as subjects. The 50 and 500 yard swim times constituted the criterion variables and were performed in a 25 yard pool. Predictor variables were determined from tests performed in a swimming flume and included aerobic power, lactate dynamic, and stroke indices variables. The maximal aerobic power tests were determined in a swimming flume using a continuous test protocol with increasing flow rates. Six submaximal flume trials of three minutes each were used to determine lactate profiles. Results: Using the stepwise regression analysis, the model accounting for the greatest variance in the women’s 500 yard freestyle included lactate dynamics measures. In the men’s and combined male and female sample, the models accounting for the greatest variance in 50 and 500 freestyle performance included stroke indices and lactate dynamics measures. Conclusion: The findings show stroke indices account for the greatest variance in the prediction of the 50 and 500 models. These variables may place differential demands on the reliance of a particular energy system depending on the distance of the swimming performance.

Index Terms: Maximal aerobic power, lactate dynamics, stroke indices, swimming flume

Introduction

This investigation described a correlational model that explained 50 yard and 500 yard freestyle swimming performance using selected measures of maximal aerobic power, blood lactate dynamics, and stroke indices in adult male and female competitive swimmers. Presently, models that describe exercise performance allow investigators to study questions relative to a specific exercise modality. Several multivariate models have been developed to predict swimming performance using either tethered swimming or simulated swimming paradigms (10,16). However, performance models using both physiological and stroke variables measured in a swimming flume have not been developed. It was anticipated that the findings of the present investigation can be used in future investigations that establish independent validity and allow coaches and physiologists to better predict performance from a standardized test administered in an aquatic environment. Such prediction models for swimming performance can aid coaches and physiologists in: 1) predicting competitive performance; and 2) tracking adaptations to training.

Swimming performance is in part determined by the interactive effects of several biomechanical and physiological variables (13). Race distances that range from 50 to 1500 meters depend to varying extents on anaerobic capacity and aerobic power (4). The relative contributions of each of these energy
systems during competitive swimming depends to some degree on pace and stroke efficiency (11). A comparatively high reliance on the phosphate (ATP/PC) and anaerobic glycolytic pathways is necessary to supply most of the energy for sprint events, with greater dependence on aerobic metabolism for the distance events. For a given speed, an efficient swimming stroke can decrease both total energy requirements and those energy requirements derived from anaerobic pathways. A comparatively greater reliance on aerobic metabolism will reflect a higher contribution of ATP supplied, postpone reliance on anaerobic performance, and help delay the onset of muscular fatigue throughout a swimming race (12).

Multiple regression models that examined anaerobic components of swimming performance have included measures of blood lactate dynamics and stroke work/power (6). To determine the magnitude of anaerobic energy yield during practice or a competitive event, measuring lactate at various points throughout the swimming distance is useful. Blood lactate is an indicator of the relative metabolic intensity during swimming. It can also serve as one index of a swimmer’s adaptation to training (8).

Aerobic metabolic components of swimming performance include measures of maximal aerobic power and stroke indices (9). The present investigation used measures of $\text{VO}_{2}\text{max}_{sw}$ ($\text{VO}_{2}\text{max}$ achieved using the freestyle stroke in a swimming flume), velocity at $\text{VO}_{2}\text{max}_{sw}$, and $\%\text{VO}_{2}\text{max}_{sw}$ at a given speed as components of a correlational model. Improvements in swimming technique and training responses can be determined by measuring the fastest speed that can be maintained at $\text{VO}_{2}\text{max}$. Swimmers who use less oxygen at a certain velocity are considered comparatively more efficient and may have a competitive advantage over those who have a high $\text{VO}_{2}\text{max}$ but demonstrate lower sub-maximal metabolic efficiency. The percentage of $\text{VO}_{2}\text{max}$ that can be used without producing fatigue is more highly related to performance in endurance events than $\text{VO}_{2}\text{max}$ (11).

Stroke indices can also be used in multiple regression models, serving as measures of economy relative to swimming performance. These involve measuring a swimmer’s stroke rate (stroke per unit time), as well as the distance traveled per stroke (distance per stroke) (13, 19). McMurray has shown the Arm Stroke Index (stroke rate) to be related to maximal swimming speed and performance time (13). Measures of stroke indices demonstrate the influence of both stroke rate and length on energy requirements at a given swimming speed.

Attempts at developing a multivariate model to predict swimming times using the anthropometric and physiologic characteristics of stroke indices and $\text{VO}_{2}\text{max}$ have been developed. Duché et al. established a relation between anthropometric and physiological data for swimming performances ranging from 50 through 400 meters (6). Klentrou et al., found that body height, maximal stroke rates, and stroke economy predicted middle distance events with the greatest power (9).

For the purpose of this study, a flume based assessment of aerobic metabolism and blood lactate production was chosen to describe those variables that are thought to explain the most variance in swimming performance time. The derived multivariate model provides the most robust description of those physiological variables (aerobic and anaerobic) that contribute to 50 yard and 500 yard swimming performance. It was hypothesized that lactate variables would describe 50 yard freestyle time with the greatest accuracy for the female, male and combined samples. It was further hypothesized the aerobic capacity variables would provide the greatest predictive accuracy for the 500 yard freestyle swimming time in the female, male, and combined samples.

### Methods

**Subjects**

The subjects used in this investigation were healthy males (n=16) and healthy females (n=12) aged 18-40 years who were currently involved in swimming training and who had participated in competitive swimming (i.e., Masters/non-collegiate) for a minimum of one year (Descriptive characteristics are presented in Table 1). Subjects were recruited through the University of Pittsburgh Masters Swimming team or aquatic classes, and participated in swim training no more than 4 days per week with their total weekly training yardage ranging from 5,000 to 15,000 yards. All subjects were required to provide written informed consent prior to the study. A questionnaire was administered to determine past and present swim training experience, “personal best” times in competitive swimming events, as well as medical history. Potential subjects were excluded from this investigation if they had for any reason been unable to fully participate in swim practices over the preceding twelve months. All experimental procedures were reviewed and approved by the University of Pittsburgh’s Institutional Review Board for Human Subjects.

**Experimental Design and Exercise Trial**

A correlational experimental design was used in which three swim flume tests and two swim performance tests were
administered. The three swim flume tests were conducted at the University of Pittsburgh Duratz Sports Complex. The tests were: (1) an orientation swim to acquaint the subject with the flume and establish intensities for experimental test protocols; (2) a swim test to measure VO2maxSw and (3) a series of submaximal swims in a single session to determine lactate threshold. Two performance swims (50 yard freestyle and 500 yard freestyle) were conducted on separate days in a regulation 25 yard pool to determine stroke rates, distance per stroke, and performance times.

Following the orientation session, subjects were assigned to a counterbalanced sequence consisting of the following tests: a) maximal aerobic power, b) lactate threshold, c) 50 yard swim; and d) 500 yard swim. Each test in the sequence was separated by approximately 7 days, and all subjects were asked to maintain current training status throughout the study.

**Experimental Variables**

The 50 and 500 yard swim times constituted the criterion variables (i.e. those that were predicted) as assessed by the performance swims. The predictor variables as determined from the three flume tests included aerobic power, lactate dynamics, and stroke indices.

**Orientation Swim**

The swimming tests were performed in the Swim Ex. flume (Swim Ex. Systems Inc., Warren, RI. Model SX600T). The flume is a 5.5 meters long x 2.43 meters wide x 1.75 meters deep tank that produces water flow rates ranging from .68 to 1.51 m/sec-1 using a paddlewheel propulsion system. Flow rates were regulated by a calibrated dial with a setting range from 1 to 8.5 units, where each .5 unit corresponded to an increase in flow rate by .09 m/sec-1. Speeds in m/sec-1 corresponding to each dial setting were calibrated by a hydrological technician using a Price AA current meter positioned 36 inches from the front of the flume at the center line and 12 inches below the water surface. The calibrated speeds showed no significant difference to speeds calculated for the same flume system at Ball State University in 1995 (unpublished, 1996).

Orientation swims in the flume were used to acquaint the subject with the testing protocols. The intensities (i.e. flow rates) for the tests were based on pre-determined relative metabolic rates determined during the orientation swim. A respiratory mask and specially designed two-way Hans-Rudolph respiratory valve (#3478) were attached to the subject's head, face, and mouth to collect expired gases. Standard temperature, pressure and dry (STPD) values for VO2, VCO2, and respiratory exchange ratio (RER) were reported every 30 seconds using an open circuit spirometry system (SensorMedics, MMC Horizon).

After obtaining resting metabolic data, 3 minute orientation swims at 4 different intensities (i.e. flow rates) were performed. The starting flow rate was that selected by the subject for the warm-up swim. Heart rates were measured from 90 to 100 seconds of each swim stage by a Polar Heart Rate monitor. The flow rate was progressively increased by .09 m/sec-1 until a heart rate approximately 85% of the subject's age predicted maximum was attained.

**Maximal Aerobic Power**

Maximal Oxygen consumption (VO2maxSw) To determine VO2maxSw (ml x kg-1 x min-1), the subjects swam in a stationary position against progressively increasing flow rates in the Swim Ex™. flume. The continuous graded swim test protocol began with a two minute stage at a flow rate that produced 85% of the subject's age predicted maximal heart rate (220 minus subjects' age) for a two minute period, i.e. as observed on the subject's last intensity during their orientation swim. After the initial two minutes, each succeeding test stage was 30 sec. in duration. The flume speed was increased by .09 m/sec-1 at the beginning of each 30 second stage until the swimmer could no longer continue due to fatigue. Criteria for attainment of VO2maxSw was: 1) a plateau or change in VO2 of < 2.1 ml/kg-min-1 with increasing flume speed 2) RER >1.10; or 3) Heart rate within 10% of the subject's age predicted maximal value for swimming. Velocity (m/sec-1) at VO2maxSw (VelVO2maxSw) was also determined during the VO2maxSw test.

**Blood Lactate Dynamics**

The swimming test to determine the lactate inflection point and predetermined levels of blood lactate accumulation consisted of six submaximal intensities of three minutes each. Stage 1 began at a flow rate corresponding to a heart rate of approximately 125 x min-1 as determined from the subject's orientation swim. Each additional stage was 3 minutes in duration. Flow rates were increased by .09 m/sec-1 for each consecutive stage. A five minute rest period in the flume separated each stage. The subjects remained in the flume during the rest period in order for the investigators to collect a sample venous of blood. This was done from the first to second minute of the rest period. A catheter inserted into a forearm vein by a phlebotomist 10 minutes prior to exercise and kept patent with saline infusion was used to sample blood. Blood samples were analyzed for lactate concentration with a YSI 2700 Select Biochemical Analyzer. Blood lactate values were plotted as a function of VO2, %VO2maxSw, and swim velocity (m/sec-1). Blood lactate dynamics were calculated by determining the lactate inflection point (Lpt) and blood lactate accumulation (BLa) levels.

**Lactate Inflection Point (Lpt)** A two-component linear regression model was used to determine the Lpt. The Lpt was determined as the power output at which there was an intersection of the slopes derived from two linear models that expressed blood lactate as a function of swimming velocity. The predictor and criterion variables that were submitted to the regression models were identified as two separate data
clusters, i.e. one describing [HLa] responses below and one above a visually discernable inflection point. The two clusters formed the separate data sets that were plotted against each other, i.e. [HLa] vs. velocity. This intersection was defined as the lactate inflection point and expressed as swimming velocity (m/sec) at Lpt (V_Lpt). The VO_2 and % VO_2 max_w equivalent to the V_Lpt were then identified similarly as VO_2 (mL/kg-1min-1) at lactate inflection point (VO_2(Lpt)), % VO_2 max_w at lactate inflection point (%VO_2(Lpt)).

**Blood Lactate Accumulation (Bla)** Blood lactate accumulation (Bla) was defined as the velocity at which blood lactate reached a value of 4.0 mmol/L-1 (7). This was observed by plotting blood lactate against the velocity of the swimming flume. The swimming velocity equivalent to blood lactate of 4.0 mmol/L-1 was identified as velocity (m/sec) at Bla of 4.0 mmol/L-1 (V_Bla). The VO_2 at a Blood lactate accumulation (Bla) of 4.0 mmol/L-1 (VO_2(Bla)), % VO_2 max_w at Bla of 4.0 mmol/L-1 (% VO_2(Bla)), VO_2 per kilogram fat free weight at Bla of 4.0 mmol/L-1 (VO_2 kg Bla); and stroke rate at Bla of 4.0 mmol/L-1 (SRBl) were also identified similarly.

**Stroke Indices**

Subjects were instructed to perform the actual swim test distances in the pool at their race pace. During each performance swim, timed splits (i.e. every 25 yards) and stroke counts per lap were completed to determine stroke rates and distance per stroke. The stroke rate during the 50 and 500 yard swims (SR50, SR500) was defined as the number of strokes divided by the total time for a given performance swim. For each flume test, stroke rate was calculated as the time to complete a 6 arm stroke cycle, and was measured at the midpoint of each stage of a flume test. The following variables were determined based on corresponding stroke rate data: Stroke rates (SR) at at Lpt (SR(Lpt)), Stroke rates (SR) at Bla of 4.0 mmol/L-1 (SR(Bla)), mean stroke rates (SR) for 50 yards (SR50), and mean stroke rates (SR) for 500 yards (SR500).

The distance per stroke (d/s) was defined as the total distance swim divided by the total number of strokes taken during the specified distance (20). During each performance swim, the mean d/s was calculated. The following variables were then determined based on corresponding distance per stroke data: Distance per stroke (d/s) at Lpt (d/s Lpt), Distance per stroke (d/s) at Bla of 4.0 mmol/L-1 (d/s Bla), mean distance per stroke (d/s) for 50 yards (d/s 50); and mean distance per stroke (d/s) for 500 yards (d/s 500).

**Data Analysis**

Data analysis was performed using the SAS/STAT version 6.12 statistical software. Pearson product-moment correlations were used to determine correlations between the physiological variables and stroke indices, and performance swim times. Those variables demonstrating significant correlations with the performance variables were included in the prediction models. Stepwise multiple regression analysis was used to construct the models to predict 50 and 500 yard performance times using physiological variables, i.e.: (1) maximal aerobic power, (2) lactate dynamics, and (3) stroke indices. Gender specific and combined sex models were constructed to explain both the 50 and 500 yard performance times. A significance level of a = .05 was used to determine the inclusion of a given physiological predictor in the stepwise regression analysis.

**Results**

**Multiple Regression Models to Predict 50 and 500 yard freestyle swim times**

All variables from the three major groupings (i.e. maximal aerobic power, lactate dynamics, and stroke indices) were submitted to stepwise multiple regression analysis. Statistically significant regression equations by sex are shown in Table 2. Regression results indicating incremental R-squares and relative contribution to variations in criterion variable are shown in Table 3.

In the female sample, no variables were significantly correlated with 50 yard freestyle swim time and as such, a prediction model could not be developed. Only VO_2 kg Bla was significantly correlated with the 500 yard freestyle swim time in the women's sample. This variable accounted for 46% of the variance in 500 freestyle times. In the men's sample, the combination of VelVO_2max_w, % VO_2 Bla, and d/s 50 provided the best model (R^2 = 0.779) to predict 50 yard freestyle time. For the 500 yard freestyle performance, a two variable model that included d/s 500 and SR Bla explained the most variance (R^2=0.874) for the men's sample. Specifically, d/s accounted for 80% and SR Bla accounted for 7% of the total variance in 500 yard swim time. In the combined sample, stepwise multiple regression analysis produced a model containing VelVO_2max_w, % VO_2 Bla, and d/s 50, as the best variable subset (R^2 = 0.706) to explain 50 yd. freestyle
time. The strongest model for 500 yard freestyle time contained only d/s 500 and vBla (R² = 0.605) with d/s 500 accounting for the majority of explained variance (54%).

Table 3. Regression Results Reflecting Incremental R-squares and Relative Contribution to Variations in Criteria Variable Men’s 50 yd Freestyle

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>Incremental R² value</th>
<th>Relative</th>
<th>Type II</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>d/s 500</td>
<td>0.92</td>
<td>1.77%</td>
<td>10.54</td>
<td>7.74</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>vBla</td>
<td>0.79</td>
<td>1.59%</td>
<td>10.02</td>
<td>5.65</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Combined 50 yd Freestyle

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>Incremental R² value</th>
<th>Relative</th>
<th>Type II</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>d/s 500</td>
<td>0.91</td>
<td>1.49%</td>
<td>10.54</td>
<td>7.74</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>vBla</td>
<td>0.77</td>
<td>1.52%</td>
<td>10.02</td>
<td>5.65</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Women’s 500 yd Freestyle

<table>
<thead>
<tr>
<th>Variable</th>
<th>r</th>
<th>Incremental R² value</th>
<th>Relative</th>
<th>Type II</th>
<th>F</th>
<th>p-value</th>
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<tbody>
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<td>10.02</td>
<td>5.65</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Multivariate physiological model to predict the 500 yard freestyle swim performance

A comparatively high VO₂max has been associated with faster swimming performance times especially in middle distance events (1, 2, 3, 9, 14, 18). Aerobic power variables were expected to account for a significant amount of variance in performance time for the 500 yd. swim. In contrast, the present investigation demonstrated that the model for the women’s, men’s, and combined samples primarily included stroke indices and lactate dynamics in explaining the 500 yard freestyle performance times.

Distance per stroke accounted for the highest variance in each of the models for the 500 yard freestyle time i.e. 80% in the men’s sample and 54% in the combined sample. Based on the present results, and those of previous investigations (19), it seems reasonable to conclude that the swimmer who takes the fewest strokes (i.e. greatest distance per stroke) at a given velocity will have better technical ability. A biomechanically efficient swimmer will consume less oxygen at given submaximal swimming speeds. Such metabolic efficiency may reflect a comparatively greater distance moved for each swimming stroke while maintaining a constant stroke rate. A reliance on aerobic energy systems at faster submaximal swimming speeds may help delay the onset of anaerobic metabolism. Collectively these data support the important role that distance per stroke and stroke rate play as variables involved in determining energy expenditure and performance time for swimming distances up to 500 yds. (2, 17, 12, 10).

Although lactate dynamics variables did not account for a large amount of variance in swimming performance time, SRBlA, VO₂ kg Bla, and vBla were significant components both the women’s and combined models. The mechanism underlying this relation may be explained by the increase in blood lactate accumulation which is assumed to reflect an increased reliance on anaerobic energy pathways during the latter portions of the swimming trial. It is important to mention that the magnitude of such a demand on anaerobic energy systems during swimming distances of 500 yards and greater will vary between swimmers. While the 500 yard freestyle swim has been considered an endurance event, Maglischo et al. found that a non-elite competitive swimmer might have as much as a 50 percent contribution from anaerobic...
bic metabolism during a prolonged swimming performance (>7 min) (12). The fact that lactate variables accounted for 7% to 45% of variance within the prediction models suggests that the 500 yard swim may place more of a reliance on anaerobic energy systems than previously reported (4).

Sex

To date, no study has examined differences according to sex in models that explain swimming performance time. Sex specific, physical, and anthropometric characteristics may offer an explanation for differential involvement of selected physiological variables that predict swimming performance (12). Siders et al. demonstrated that the 100 yard freestyle sprint performance time of female swimmers was significantly correlated to height ($r = -0.76$), fat free body weight ($r = -0.657$), and total body weight ($r = -0.437$) (15). Siders also showed that a high ectomorphic somatotype of comparatively greater lean body mass and longer limb length were associated with freestyle sprint performance ($r = -0.441$). This suggests that a dominant ectomorphic somatotype is related to a greater generation of power and a faster freestyle sprint performance. Such physical and somatotype characteristics were not investigated in the present study. Based on the present findings, a more extensive examination of anthropometric characteristics relative to power and swim performance appears justified. Such research may help explain the absence of a significant correlation between certain physiological variables known to be influenced by body composition and freestyle sprint performance in the present investigation.

Conclusions and Applications

In the present investigation, several of the same physiological and stroke/work variables significantly contributed to both the 50 yard and the 500 yard swim performance times. Based on the apparent utility of these findings, it is proposed that cross validation of the described models to explain swimming performance times be conducted for the 50 and 500 yard models. It is also suggested that prediction models using distances greater than 500 yards be developed to determine the extent to which there is a differential reliance on aerobic and anaerobic metabolic pathways.

From a practical perspective, protocols that employ a multiple regression model should be developed for use in a pool setting. An exploration of how stroke characteristics and muscular power of a swimmer might place differential demands on a given energy system is suggested for future research. In this context, a test could be developed to specifically measure muscular power during swimming. Such a test may help to determine the role that $\text{VelVO}_2\text{max}_{ex}$ and distance per stroke played in determining swim performance time for both the sprint and middle distance trials in the present investigation. Likewise, the lactate dynamics variables measured in the present study required an invasive technique that demanded a great deal of assessment time and subject cooperation. A validated poolside protocol could overcome these methodological limitations by using repeated high intensity swimming trials to estimate anaerobic energy requirements. Poolside values could then be used to predict anaerobic energy contributions, swim performance, and stroke indices relative to a particular swimming race distance.

In conclusion, it was found that measures of lactate dynamics, aerobic power, and stroke indices were related to 50 yard freestyle performance time in the male only and combined female and male samples. A combination of lactate dynamics and stroke indices were related to 500 yard freestyle performance in the female, male, and combined sample. The strong and consistent presence of stroke indices variables in the models for the 50 and 500 yard performance distances suggests that both $d/s$ and stroke rate are among the primary determinants of swimming performance. These two variables may place differential demands on the reliance of a particular energy system depending on the distance of the swimming performance.

The results of the present study should encourage coaches to examine the relation between stroke mechanics and the physiological variables surrounding the aerobic and anaerobic energy systems. This supports current trends in competitive swimming that suggest the important role of proper stroke and body mechanics in improving swimming economy. In addition, the critical role of recognizing aerobic and anaerobic energy contributions as determined from blood lactate measures to assist in developing training progressions that will improve overall swimming performance should be encouraged.

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Note

References were obtained from Medline and SportDiscus with keyword "swimming" for journal articles and books published in English during 2002 and 2003. In order to narrow the focus of the In Print bibliography, articles that do not contain a significant coaching, scientific, or research emphasis were eliminated.

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“Psychophysiological effects of competitive stress on swimming coaches”
1. The present study showed that somatic anxiety peaked at _______ of the championships, whereas cognitive anxiety _______.
2. In the present study physiological and psychological measures of anxiety were or were not related? _______.
3. The contradiction between the present study and the studies of Kugler et al. (1996), as well as Kirschbaum et al. (1998), could be explained by _______ experienced by the swimming coaches.

“A comparison of selected kinematic variables between races in national to elite male 200 m breaststroke swimmers”
1. After swimming velocity which variable accounted for the most change in performance between the two races?
2. What percentage of the improvement in race finishing time was attributed to the change in the start time _______.
3. Researchers have debated for some time whether stroke rate, stroke length or both increase when elite swimmers improve their swimming velocity in competition. What was the outcome in this study?

“Rapid correction of start technique in an Olympic-level swimmer: a case study using old way/new way.”
1. The alternative approach, termed old way/new way, holds that consistent, habitual errors indicate _______.
2. When new knowledge or a new skill disagrees or conflicts with what a person already knows, this conflict generates _______.
3. In the present study, a permanency in technique correction was observed in performance of as many as _______ of correct starts during two weeks following the intervention (learning trial).

“Peak oxygen uptake responses to free and simulated swimming using different body segments”
1. The difference in peak oxygen uptake responses to whole-stroke free and simulated swimming was shown to be _______.
2. No significant differences were found in peak oxygen uptake responses in free and simulated swimming between arms-only and _______ exercise.
3. Possible limitations in the use of simulated swimming have included immersion-induced bradycardia, chest compression limiting ventilation at high exercise intensities, _______.

“Determining the effectiveness of the taper for a division III swimming program utilizing cardiopulmonary function values.”
1. Improved cardiopulmonary function values at the end of the taper (just post-competition) may correspond with the improved level of performance to validate the effectiveness of the taper regimen. TRUE or FALSE
2. An individual swimmer’s response to exercise-induced fatigue may be measured by cardiopulmonary function and that may be useful in seasonal training planning and in assessing the swimmer’s improvement throughout the season. TRUE or FALSE
3. At maximum exercise, the difference in testing swimmers on a treadmill or bicycle has been shown to be significantly different that with a flume. TRUE or FALSE

“Prediction of Performance Using Physiological and Stroke Variables in a Sample of Adult Competitive Swimmers”
1. What two “stroke” variables represent the major influences on swim velocity, especially the 50?
2. The strongest prediction of 500 yard freestyle time in the combined sample was provided in a model containing the following variables: _______, with an R2 of _______.
3. Blood lactate accumulation (Bla) was defined as the velocity at which blood lactate reached a value of _______.
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