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Side effects

Usually, the term “side effects” is associated with negative connotations; an undesirable or unanticipated effect of a medical treatment or drug therapy. For example, one well known negative side effect of taking aspirin is gastric bleeding. Ibuprofen use can cause tinnitus (ringing in your ears). But side effects don’t always have to be negative. They can also be positive. For example, the side effect of Minoxidil, an agent designed to control blood pressure, is unanticipated hair growth. It is now marketed world wide as Rogaine. Thus, for the moment, it might be timely to consider several important ‘side effects’ of involvement in competitive swimming.

The intended effect of swim training is simply this: swimming faster. Getting down the pool and back in as little time as possible is the primary intent of competitive swim training. However, one could argue that the ‘side effects’ of competitive swim training are every bit as important, if not more so than swimming faster. What are these important side effects? Goal setting, self discipline, time management, team work, self confidence, commitment and so on and so forth are perceived as important side effects of competitive swimming. Improved health and wellness are two more, and these two should be pretty high on a ranking of relative importance. At the moment, health and wellness seem to be the domain of United States Masters Swimming, a significant mistake made by our sport. It can be argued that health and wellness should be a central issue for all of us rather than merely a peripheral one.

In case you haven’t read or heard about this already, childhood obesity is rapidly becoming the epidemic of the 21st century. The USGAO (United States Government Accountability Office) reports “obesity rates for children 6 to 11 years old are estimated to have increased from 15.1 to 18.8 percent between 1999 and 2004. The US Department of Health and Human Services estimates that 20 percent of children and youth in the United States will be obese by 2010.” Furthermore, children who are obese have a much greater chance of being obese as adults then those who are not. It is as simple as that.

It is becoming ever so clear that there is a price to pay for this epidemic. According to one governmental estimate, insured obese children are approximately three times more expensive for the health care system than the average weight insured child. We are not talking then about theoretical costs but real dollars and cents. And they are costs that will not go away over time. They will only get worse as these children mature into adults. But perhaps more troubling than the financial concerns, it has been predicted that for every child born after the year 2000, one out of three Caucasian children in the USA and nearly twice that many Hispanic and African Americans children will become diabetic. Dr Ken Cooper, of the Cooper Aerobics Institute in Dallas, TX, states emphatically, “if a child develops Type II diabetes before the age of 14, data suggests that their life may be shortened by as much as 27 years.” The shortened life span of our nation’s children is perhaps the highest price of all.

And if you think that this problem is unique to the United States, you are badly mistaken again. The problem we face here in the US is simultaneously being faced by nearly every developed nation in the world.

While there are many different definitions of obesity, commonly, adult men over 25% and women over 30% fat by weight are classified as obese. This theoretically corresponds to a BMI over 30 and/or body weights between 20 and 30 pounds over ideal body weight. There is no agreed upon definition for obesity in children. However, most definitions are similar to those applied to adults. And again, the real concern is that in adults, obesity is associated with, and a primary contributor towards, Type II (adult-onset) diabetes, high blood pressure (hypertension), stroke (cerebrovascular accident or CVA), heart attack (myocardial infarction or MI), congestive heart failure, cancer (such as cancer of the prostate and cancer of the colon and rectum), gallstones and gall bladder disease (cholelithiasis), gouty arthritis, degenerative arthritis of the knees, hips, and the lower back, sleep apnea (failure to breathe normally during sleep, lowering blood oxygen), and Pickwickian syndrome (obesity, red face, underventilation, and drowsiness) (MedicineNet.com). These are appropriately considered the ‘side effects’ of obesity. Need I go on?

So where does competitive swimming fit into all of this? The limited data from swimmers suggest several things. The first is that very few swimmers can be classified as “obese.” The percent fat of age group swimmers is between 5% and 10% below the values available for age matched children in the general population. By comparison, absolute values (in pounds of fat), would place age group swimmers’ body fat at about half that of comparably aged controls. College age male swimmers have been...
reported to have between 5% and 10% fat and college aged women swimmers between 12% and 18% fat. Their sedentary counterparts record values on average between 15% and 20% for men and between 25% and 30% for women. Most impressive of all is new data from Masters Swimmers where less than 20% can be considered over weight and only 5% can be classified as obese. This is a pretty important and very significant “side effect” of competitive swim training. One that is certainly worth taking note of and clearly demanding of further consideration!

For a moment, the underlying causes of obesity need brief mention. Although somewhat simplified, it comes down to this: energy in and energy out. Realize please, that body weight and body composition are more complicated than this. There are complex neuro-endocrine responses involved as well. This is certainly true. But in simplified form, it really is about how many calories are you eating and how much energy are you expending over the long haul. In the 21st century, the easy availability of food has caused an imbalance between the energetic cost of producing the foodstuff and the easy consumption of it. There are many, many food choices children are allowed to make, and many of these choices are bad.

The other side of the equation, however, is the nearly complete loss of state mandated physical activity programs in schools. Simultaneously, societal changes have virtually eliminated ‘free play’ which has also acted to reduce the daily activity and energy expenditure of our youth. With both parents working, the unsupervised sand-lot kick ball, baseball, tag, tackle hill dill, etc. have virtually disappeared. “Big screen TVs”, the internet, video games, hand held entertainment devices, etc. all compete for a child’s free play time, as limited as it may be. And this is where competitive swimming and its various iterations come in. Swim training programs clearly result in “side effects” that convey significant important benefits from these specific perspectives.

As mentioned previously, there exists limited data on the body composition of young swimmers. Much of this data is more than twenty years old. The majority pertains to highly talented or the most successful swimmers. Nevertheless, that which does exist supports the conclusion that swimmers are remarkably leaner than their sedentary counterparts. This appears to be true for every age group including Masters Swimmers. While few outside the swimming community will be surprised at this, it would seem that we allow this fact to go largely ignored. Why not aggressively pursue relationships and partnerships with entities whose missions are focused directly upon the health and wellbeing of our children? Some might say this is self serving of our sport. You could argue that the intent makes little difference if the eventual outcome is positive and promotes increased fitness and a reduction in the prevalence of childhood and adult obesity.

You could also suppose that this initiative could become part of the marketing strategy for FINA, ASCA, NSPF, USA-Aquatics (and all swimming international governing bodies) including USMS. It is an initiative we can not ‘not undertake’. Winning an Olympic Gold medal might be important from the perspective of confirming our commitment to excellence and the success of our respective ‘way of life.’ But helping to solve one of the great challenges facing today’s human society is much less ethereal.

Once again, I would like to extend thanks to all those who have contributed to this issue of JSR. Without the ‘volunteerism’ displayed by the reviewers and editors, secretaries, graduate students and authors, this issue would never ever go to press. Once more, a special thanks is extended to the members and administrative staff of the American Swim Coaches Association for their continued support of the Journal.

Dr. Joel Stager, Editor
Effect of EMDR on Anxiety and Swim Times

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Abstract

This study investigated the effect of Eye Movement Desensitization and Reprocessing (EMDR) on swimmers who had experienced a traumatic swimming event. Measures of performance, anxiety, and self-perception in (N = 65) competitive college and high school swimmers were collected. Swimmers were randomly assigned to one of three conditions: EMDR, imagery or no treatment. All participants took the State-Trait Anxiety Scale and performed a 100 yd freestyle swim pretreatment and posttreatment. The EMDR and imagery group had two additional anxiety measures: [heart rate and Subjective Units of Distress, (SUDS)] and one cognition scale the Validity of Cognition Scale. These two groups had three sessions of either EMDR or imagery. Trait anxiety scores did not differ among groups as expected but the EMDR group’s state anxiety decreased compared to no treatment group p = .002. Heart rate and SUDS decreased as a consequence of group, with EMDR showing a drop in rate p < .001. Swim times were not different for all the groups, but EMDR improved compared to the no treatment p = .043. The EMDR group endorsed greater coping beliefs than the imagery group p < .01. EMDR may provide coaches with an alternative to imagery to help the athlete who has a “mental block” (negative thoughts indicating inability to cope with the swimming event) secondary to a traumatic sport event.

Key words: EMDR, anxiety, mental block & competitive swimmers

Introduction

This study investigated the effect of Eye Movement Desensitization and Reprocessing (EMDR) on swimming performance, anxiety and self assessment of ability to cope regarding a swimming event, after having experienced a traumatic swimming incident. A traumatic swimming incident was considered an incident the athlete described as the “worse” swimming incident where (he) experienced embarrassment or humiliation and these thoughts intruded into consciousness prior to engaging in a swim competition. The study was conducted with division III competitive college and high school swimmers. When individuals have perceived a situation negatively and have created negative cognitions about the experience, it is often a reflection of their perceptual style (2). Bandura further suggested that positive visualization enhances self efficacy, (the belief in one’s ability to manage a situation) by reciprocally inhibiting negative visualizations.

This negative interpretation of the event predisposes the individual to react in a manner indicative of poor self-efficacy. An individual’s cognitive interpretation of the anxiety may have an important impact on performance; if one adopts a catastrophe model of performance in sport, it may negatively impact performance (19).

The relationship between anxiety and performance has been studied extensively in the past (16, 22, 23). The earliest explanation of the relationship of anxiety to performance was the Yerkes-Dodson Inverted—U Hypothesis (32). This acted as the stepping stone for new models. The Multidimensional Theory of Anxiety is made up of a cognitive and a somatic division. The somatic is the physiological effect of anxiety evidenced by arousal of the Sympathetic Nervous System (SNS). The cognitive component of anxiety is the automatic negative thoughts that intrude into one’s consciousness concerning the possible outcome of the upcoming event (3).
A shortcoming of this model is the separation of the two components of soma and cognition.

The Catastrophe Model includes an interaction of cognition and physiological arousal (14). Sympathetic Nervous System arousal can influence performance as a result of the athlete's interpretation of their physiological symptoms. Cognitive anxiety accompanied by low levels of physiological arousal has little effect on performance. As the levels of physiological arousal increase accompanied by negative cognitions then performance may increase or decrease (13). Once a certain level of physiological arousal is reached there is a dramatic drop in performance, a catastrophe occurs and can only be reversed by a reduction in the physiological arousal. Hysteresis will follow when high cognitive anxiety is present a negative correlation with performance will subsequently follow (14). Hardy, Parfitt and Pates (15) stressed that the hysteresis is person specific, suggesting individual reactions to anxiety.

There have been a number of studies with differing conclusions regarding the relationship between somatic and cognitive aspects of anxiety (21). Krane (20) indicated that studies have continued to examine the two components independent of each other without regard for the multidimensional nature of anxiety. Parfitt, Jones and Hardy (26) stated "it is the effect of the changing anxiety levels upon an individual's actual performance that is important, not how the scores vary between individuals with different anxiety levels", (p.54). Hardy and Parfitt (15) stated when individuals are cognitively anxious they continue in their attempts to deal with the demands of the task. However, the physiological arousal could interfere with their performance by distraction, reducing their capacity to process cognitive information. Or the physiological arousal could result in them consciously diverting their cognitive resources to maintaining effort, rather than to the successful performance of the task. Research conducted with an elite group of swimmers found that anxiety intensity levels were higher in subjects who interpreted their anxiety as debilitating, in contrast to those who reported it as being facilitative (18).

The Zone of Optimal Functioning (ZOF) hypothesis (11) further explores individual responses to anxiety. Hainin interprets the variation that exists among athletes' individual zones of precompetition state anxiety necessary for optimal performance. Optimal performance will occur when the athlete's precompetition anxiety falls within his or her predetermined zone of optimal functioning. This model incorporates both positive and negative affects on athletes (10). He has a multidimensional model, which has five basic components to describe performance-related emotional states. His model includes the following components: intensity, context, form, time and content. He notes that when athletes described their worse ever performance the stress related emotions that were associated were anger, anxiety, sadness, shame and fright. The in-out of the zone notion was proposed to describe the range of emotion intensity producing optimal, neutral, or dysfunctional effects upon individual performance. This in-out of the zone has received strong empirical support (10). Hain in dispels the fallacy that negative emotions are always counterproductive to performance. He advocates for individual emotion profiling (IEP) based on idiographic recall using the athlete's metaphors. Davis and Cox (6) found support for the Individual Zone of Optimal Functioning (IZOF) model relative to the intensity of the cognitive anxiety with swimmers.

Imagery has been suggested as one technique to reduce the precompetitive state anxiety. Imagery and cognitive-behavioral techniques have been shown to reduce anxiety. This reduction induces the perception of competition as nonthreatening improving performance in swimmers (25). A literature review of imagery in sport concluded that most cognitive specific motor skills imagery studies have found a facilitation of learning, acquisition and performance of those skills imagined (21).

This study attempted to investigate athletes who had experienced a traumatic swimming event. The swimmer was requested to focus on the "worse" swimming incident they had ever experienced. The event must have been one that is cognitively replayed as they prepare to swim. The specific incident, cited by the athletes brought upset emotional, cognitions, visual images and physical sensations. This is different than the research previously reviewed on precompetitive anxiety, because it is not one where the athlete is merely unsure and anxious about swimming but one in which the athlete previously experienced a humiliating or embarrassing experience. These events would be representative of the debilitating cognitions and high levels of anxiety discussed by Hain and others. This traumatic swimming event would be out of the ZOF.

Eye Movement Desensitization and Reprocessing (EMDR) has been used extensively with Post Traumatic Stress Disorder (1,5,7,30, 31), but there is little knowledge in the area of EMDR and performance anxiety (24). This study was an attempt to serve as a pilot to bridge the gap between a therapeutic technique and the field of athletic performance in swimming. Most of the work in this area to date has been anecdotal with athletics. EMDR uses bouts of 20-40 rapid, saccadic eye movements by requesting the athlete visually track a light, which moves laterally in sequence from left to right. EMDR was discovered by Francine Shapiro (27) who found that this technique resulted in the brain processing information in much the same manner as during rapid eye movements (27). Shapiro believes this facilitates the ability to reprocess traumatic memories into a more adaptive or coping schema. This process requires the individual to visualize an upsetting sports event and reprocess that event employing all senses, and simultaneously cognitively reframe the experience.
The process of imagery does not include processing a traumatic competitive sport event. Similarities between imagery and EMDR exist, in that both procedures result in a relaxation response. The EMDR protocol however has the added aspect of reprocessing the unpleasant sport event and “reliving” it via the senses. Foster and Lendl (8) used EMDR to enhance performance in athletes and as a tool for executive coaching. Crabbe (4) used the technique to improve riders’ performance in dressage competition.

The purpose of this study was to investigate the effect of EMDR in reprocessing a traumatic swimming event and its’ effect on anxiety, self-perception of performance and actual performance in competitive swimmers. EMDR was compared to imagery and a no treatment condition as a technique to decrease anxiety and increase performance. EMDR as a technique to enhance performance in competitive athletes is a natural extension of the work in the area of performance enhancement. Athletes who have experienced an upsetting competitive incident are an important subgroup of competitive athletes who have difficulty with competitive anxiety. This group not only perceives competition negatively but is driven by the prior trauma which is relived. As a result of the relieved experience the swimmer will approach competition or contemplate competition with increased levels of cognitive and physiological anxiety. The technique of EMDR is well established as a tool to help people reprocess trauma in the therapeutic setting and has been investigated both on a physiological and psychological level (4, 8,30,31). The cognitive reinterpretation of the upsetting competition experience was expected to be reprocessed in a more positive light in the EMDR group, which would translate into the physiological reduction in anxiety.

It was expected that athletes’ precompetition anxiety (state) would decrease both by self report and by physiological recordings (heart rate) as a consequence of the EMDR, while the trait anxiety would not. Trait anxiety was not expected to change because it is an enduring characteristic of the individual. Swimming performance (100 yard time trial) was expected to increase as a result of the reduction in anxiety and positive reframing of the cognitions (VoC). The hypotheses were tested by random assignment of a convenience sample to one of three conditions; EMDR, imagery or no treatment. Imagery was used as a comparison to the EMDR group.

Method

Participants

Volunteers were recruited from four competitive swim teams a division III state college, two Y.M.C.A.’s, and a public high school. Participants were without compensation. Volunteers were required to be at least 16 years of age, with at least three years of swimming competition experience. Participants ranged in age from 16 to 21 years of age, with a mean age of 16.97 years (SD = 1.98). There were 43 women and 22 men. There were 71 volunteers originally, but due to sickness and missed appointments, six were dropped from the study resulting in 65 participants. There were 21 participants in the EMDR group, 22 in the imagery group and 22 in the no treatment group. Informed consent was signed by the participants or their parents if the swimmer was under eighteen. Institutional Research approval was given by the IRB board at Bridgewater State College.

Measures

Anxiety. State-Trait Anxiety Inventory for Adults (STAI) is a self-report instrument designed to measure separate but related anxiety concepts (19). It has two 20-item scales for measuring state and trait anxiety in which participants rated anxiety items from 1 (almost always) to 4 (almost never). Total scores range from 20 to 80 and a higher total score represents greater anxiety with norms for high school and college students. The Subjective Units of Distress Scale (SUDS) has been used with systematic desensitization and EMDR. Wolpe (31) developed the SUDS scale, which involves the participant rating their level of stress on a continuum from 0 (no disturbance) to 10 (highest disturbance). The SUDS rating has been found to correlate with objective physiological indicators of stress (29). Heart rate was measured by having the participants take their pulse and verbalize the pulse count while focusing on the traumatic event as the researcher timed them for six seconds. Acknowledging that there are many individual differences in arousal response, including a physiological and self-report measure, the construct of anxiety was assessed in a bodily and cognitive domain. The heart rate was taken as the participant was visualizing his or her most traumatic swimming event and rated on the SUDS scale. An incident qualified as “traumatic” if the athlete rated it above a 5 on the SUDS scale and verbalized a noncopying statement on the VoC scale, scoring below 4. This ensured that the incident was in fact viewed as traumatic to the participant.

Self-Perception. Validity of cognition (VoC) is part of the EMDR protocol. It is a self-perception measure that Shapiro (18) named the Validity of Cognition VoC. The person composes a positive self-belief statement in the context of a specific traumatic event such as an athletic performance. This belief is rated on a 7-point scale from 1 (completely false) to 7 (completely true). Two 100 yard freestyle swim time trials were conducted by the swim coaches pretreatment and posttreatment. Time trials were administered and timed (Robin Stopwatch) by the team coaches.

Apparatus & Materials

LapScan 2000 (Neuro Tek Corp.). A LapScan is an eye scan machine the size of a large lap top computer which displays a moving light that the volunteers track with their eyes. The LapScan was chosen for the project to standardize
the EMDR technique with each volunteer. Speed and consistency are maintained with the LapScan versus a clinician.

Imagery audiotape. An audiotape was made by the principle investigator for the imagery group. The audiotape for the imagery sessions ensured standardization of the treatment variable. The 30 minute tape is a voice recording instructing the participants to imagine time slowing down and requests that they imagine walking into a peaceful scene or situation of their choosing. The instructions guide the participants through each of their five senses and requests that they experience the scene they chose through each of their senses, one at a time.

Procedures

Design. The dependent measures examined were the following; anxiety measures (STAI, SUDS, and heart rate), self-perception of coping (VoC) and swimming performance (a 100 yard freestyle time trial pretreatment and posttreatment). The independent measures were the treatment conditions; EMDR, imagery and no treatment. Heart rates were taken by the participants with the investigator. SUDS and VoC ratings were taken according to the protocol for the EMDR and the imagery group twice at each session. The first recording occurred at the beginning of each session, when the upsetting sport experience was recollected while the second occurred at the conclusion of the session when the participant again recollected the traumatic event.

The analysis of the SUDS, heart rate, and VoC for the EMDR and imagery groups were conducted during the first recording at session one and the last recording at session three. The differences in scores from pretest to posttest were analyzed by a mixed ANOVA repeated measures pairwise comparison analysis for all the measures except the VoC scale. All levels of measurement were interval level except the VoC, which was ordinal. The Mann Whitney U test was used to analyze the VoC score differences. The STAT analyses were conducted on the pretest and posttest scores. An alpha level of .05 was used for all statistical tests.

Swimming performance was measured using two 100 yard freestyle trials that were conducted by the coaches at their practices, one pretreatment and one posttreatment. Athletes were randomly assigned to one of the three conditions. All three groups completed the STAI prior to the initiation of the treatment intervention and posttreatment. Coaches were blind to the randomization of their athletes. The imagery and the EMDR group each had three sessions with the additional measures of heart rate, SUDS and VoC taken twice at all sessions. The imagery group participated in three sessions of imagery exercises while focusing on an upsetting swimming memory in the first two sessions. The EMDR group followed the standard EMDR Level I protocol for the first two sessions (27). During the first two sessions the two groups focused on an upsetting competitive event while in the third and final session the focus shifted to a perfect or ideal swimming performance. The EMDR sessions were all conducted by the same psychologist trained in Level I and Level II of EMDR by the Francine Shapiro institute of EMDR. The Imagery sessions were conducted by a Masters’ level counseling student.

EMDR. The purpose of EMDR is to facilitate cognitive reprocessing, so that an individual is able to secure all the learning possible from a given experience, and interpret that information in the most positive light for personal growth. The EMDR group focused on their worse swimming competitive experience to investigate the possibility of reprocessing this in a positive format to impact favorably on future competitive performance. The actual desensitization of the anxiety-provoking event began with the athletes focusing on that event as they began the eye movements. The researcher induced bouts of (20-40) rapid, saccadic eye movements by requesting the athlete to visually track a light, which moves laterally in sequence from left to right. The usual result after a fifty-minute session is some type of shift in the image, the belief or body sensation. The cognitive shift usually is toward a more coping interpretation of the experience. The standard EMDR protocol was followed (27).

Imagery. The imagery group followed the same protocol as the EMDR group, except in lieu of the EMDR procedure the imagery group listened to a recorded imagery audiotape. This was the only difference in the two groups.

Results

Descriptives

The study sample (N = 65) had 22 men and 43 women. The mean age of the participants was (M = 16.97, SD = 1.98) with an age range of 16-21 years. There were no significant age differences among the three groups (p = .87). Gender was evenly distributed in each group. There were no score differences across treatment groups on the psychological measures of the State-Trait state scale (p = .71) or the State-Trait trait scale at baseline (p = .87).

Anxiety

State. State anxiety was hypothesized to decrease as a result of the EMDR intervention over the other two groups. State anxiety main effect for pretest and posttest scores was not significant, F(1, 62) = 1.93, p = .17. Main effect of group was not significant, F(2, 62) = 2.24, p = .115. The group X state condition interaction 2 (repeated measures: pretest, posttest) X 3 (condition: EMDR, imagery, no treatment) mixed ANOVA was significant, F(2, 62) = 6.84, p = .002, N2 = .18. Figure 1 presents anxiety scores for the EMDR group evidencing anxiety scores decreased, from a pretest (M = 35.29, SD = 9.09) to a posttest (M = 29.48, SD = 7.97) while the imagery group anxiety scores essentially remained unchanged from a pretest (M = 34.32, SD = 7.49) to a posttest (M = 34.77, SD = 8.75) and the no treatment group scores increased from a pretest (M = 36.36, SD = 8.12) to a posttest (M = 38.05, SD = 8.21). Pairwise comparison of groups mean
differences, with a decrease for the EMDR group (-4.824) over no treatment group \( p = .039 \), but not for the imagery group (-2.165).

**Trait.** It was hypothesized that the trait scores would not decrease as a function of treatment, because trait is an enduring characteristic of the individual. Trait anxiety pretest and posttest scores for main effect was not significant, \( F(1, 62) = 1.31, p = .26 \). The main effect for group was also not significant, \( F(2, 62) = .16, p = .86 \). The group x trait condition interaction 2 (repeated measures: pretest, posttest) X (condition: EMDR, imagery, no treatment) mixed ANOVA interaction was not significant, \( F(2, 62) = 1.50, p = .23 \).

**Heart rate.** Heart rate was measured as a physiological measure of state anxiety. Pretest and posttest heart rates main effect was significant, \( F(1, 41) = 20.76, p < .001, N^2 = .34 \). Main effect between group was not significant, \( F(1, 41) = .39, p = .53 \). The group x heart rate condition interaction 2 (repeated measures: pretest, posttest) X 2 (condition: EMDR, imagery) mixed ANOVA interaction was significant, \( F(1, 41) = 23.22, p < .001, N^2 = .36 \) as presented in Table 2. Levene’s test for equality of variances was significant, indicating unequal variance across groups’ heart rates. Histograms were examined for large differences in variances or outliers and none was found. The EMDR group’s heart rate decreased from pretest \( (M = 93.10, SD = 16.62) \) to posttest \( (M = 73.57, SD = 10.39) \) whereas the imagery group’s heart rate pretest \( (M = 79.77, SD = 24.42) \) did not change notably to posttest \( (M = 80.32, SD = 19.33) \) as presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Testing Time</th>
<th>EMDR</th>
<th>Imagery</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>M</td>
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</tr>
<tr>
<td>SD</td>
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<td>24.42</td>
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<tr>
<td>Post-Test 1</td>
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<td>80.32</td>
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<tr>
<td>M</td>
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<td></td>
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<tr>
<td>SD</td>
<td>10.39</td>
<td>19.33</td>
</tr>
<tr>
<td>Pre-Test 2</td>
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<td>5.22</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
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<td>2.34</td>
</tr>
<tr>
<td>Post-Test 2</td>
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</tr>
<tr>
<td>M</td>
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<td></td>
</tr>
<tr>
<td>SD</td>
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<td>2.48</td>
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</tbody>
</table>

### Table 2

**Analysis of Variance for Main Effects and Interaction Effect of Heart Rate**

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>( \eta^2 )</th>
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</thead>
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<td>Heart Rate</td>
<td>1</td>
<td>1934.91</td>
<td>20.76**</td>
<td>.34</td>
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<tr>
<td>Groups</td>
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<td></td>
<td>1.16</td>
<td>.39</td>
</tr>
<tr>
<td>Heart rate X group</td>
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<td>2163.75</td>
<td>23.22**</td>
<td>.36</td>
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<tr>
<td>Error</td>
<td>41</td>
<td>93.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note.** \( \eta^2 \) = effect size.

* \( p < .01 \).

**SUDS.** SUDS ratings and heart rate have been shown to correlate. It was hypothesized that the SUDS ratings for the EMDR group would decrease as a consequence of reprocessing the traumatic event. SUDS were measured as a collateral measure of heart rate and state anxiety. Pretest and posttest SUDS scores main effect was significant, \( F(1, 41) = 102.64, p < .001, N^2 = .72 \). Between groups main effect was not significant for SUDS \( F(1, 41) = .17, p = .68 \). The group X SUDS condition interaction 2 (repeated measures: pretest, posttest) X 2 (condition: EMDR, imagery) mixed ANOVA interaction was significant, \( F(1, 41) = 24.87, p < .001, N^2 = .38 \) as presented in Table 3. The EMDR’s ratings of distress...
decreased from pretest ($M = 6.57, SD = 2.06$) to posttest ($M = 1.76, SD = 1.67$) more than the imagery group's pretest ($M = 5.22, SD = 2.34$) to posttest ($M = 3.59, SD = 2.48$) but the pairwise comparison between groups for the SUDS mean difference was not significant $F(1, 41) = .17, p = .68$ as presented in Table 1.

**Table 3**

**Analysis of Variance for Main Effects and Interaction Effect of Subjective Units of Distress (SUDS)**

<table>
<thead>
<tr>
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<th>MS</th>
<th>$F$</th>
<th>$\eta^2$</th>
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<tbody>
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<td>SUDS</td>
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<td>102.64**</td>
<td>.72</td>
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<td>SUDS X group</td>
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<td>54.10</td>
<td>24.87**</td>
<td>.38</td>
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<tr>
<td>Error</td>
<td>41</td>
<td>2.18</td>
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<td></td>
</tr>
</tbody>
</table>

*Note. $\eta^2$ = effect size.

*p < .01.

**Swim Time.** It was hypothesized that the 100 yard freestyle swim times for the EMDR group would decrease as a consequence of the reprocessing the traumatic swimming event. Pretest and posttest 100 yard freestyle swim times main effect was not significant $F(1, 62) = .007, p = .93$. Main effect for between groups swim times was not significant, $F(2, 62) = 2.41, p = .09$. The group X swim time condition interaction 2 (repeated measures: pretest, posttest) X 3 (condition: EMDR, imagery & no treatment) mixed ANOVA interaction was not significant, $F(2, 62) = 1.22, p = .30$. Pairwise comparisons between groups for the 100 yard freestyle swim for EMDR ($M = 65.33$) compared to no treatment ($M = 72.74$) $p = .043$ as presented in Figure 2. But no difference emerged between the EMDR ($M = 65.33$) compared to Imagery ($M = 72.74$) $p = .043$.

**Validity of Cognition**

The analysis was conducted the first recording at session one and the last recording at session three. The post-study score was subtracted from the first session first score. A Mann-Whitney U Test was used to compare the resulting difference of the two scores. The observed valued was $U = 94.0$ indicating that the EMDR group ($M = 15.48$) was significantly lower than the imagery group ($M = 28.23$), $p < .00$. A lower net score indicates a coping response concerning the traumatic event.

**Discussion**

A therapeutic technique, Eye Movement Desensitization and Reprocessing (EMDR), which has been extensively used for desensitizing and reprocessing traumatic experiences (1,7,5) was investigated to ascertain if it enhanced performance in competitive swimmers, who had experienced a traumatic swimming event. The hypothesis was the procedure would decrease momentary anxiety and facilitate a cognitive reframing of the event into more adaptive coping cognition. Competitive swimmers were randomly assigned to one of three conditions; no treatment, imagery or EMDR. The EMDR group and the imagery group followed identical procedures, with the exception of the treatment variable EMDR versus imagery. These two groups completed the following three measures, Validity of Cognition, Subjective Units of Distress and heart rate. All three groups completed the State-Trait Inventory and participated in a 100 yard trial freestyle swim prior to the study and at conclusion of the study. None of the groups was significantly different in age, gender or on the State-Trait Scale at baseline measure. None of the participants had used mental imagery or EMDR previously in training.

Trait anxiety was not expected to significantly differ among the three groups and did not, because this is an enduring characteristic of the individual. It was expected that the EMDR group would decrease on the State-Trait (state) measure as a consequence of the treatment. There were no main effects for state or total sample pretest to posttest differences, but there was a significant interaction effect for
state anxiety by group. The EMDR state anxiety decreased, the imagery and no treatment remained essentially unchanged, and the total mean comparisons for the groups did not differ. The pairwise comparison revealed the EMDR group decreased more than the no treatment group. These results may indicate that it was not the passage of time that accounted for a reduction in the participants' anxiety. The total anxiety score did not differ by condition, but a large change was exhibited in the EMDR group. EMDR was hypothesized to decrease state anxiety (1, 7, 5). The technique required the athlete focus on the "worse" or traumatic sport experience and was not expected to have an overall effect on personality traits or trait anxiety.

Heart rate has been shown to correlate with the Subjective Units of Distress Scale (20). There was a main effect for time with heart rate. All participants' heart rates decreased over time, while the overall means did not differ. This may be a physiological effect of the relaxing effects of both of the procedures imagery and EMDR. But the EMDR evidenced a greater decrease in heart rate than the imagery group over time. EMDR has been reported to facilitate the participant to relieve the traumatic experience, which has been cognitively and physiologically stored (27). This may account for the higher initial heart rate in the EMDR group than recorded the in the imagery group. An interaction effect for each group from pretest to posttest revealed significant differences depending on the group. The EMDR group evidenced a reduction in heart rate compared to no change in the imagery group. This may be due to the autonomic arousal and "reliving" induced by the EMDR, which is different from imagery (1, 5, 7). Imagery is focused on a positive mental image. The total means for the groups did not differ.

The Subjective Units of Distress was viewed as a collateral measure of anxiety for cognitive aspects. There was a main effect for time, with all participants' heart rates decreasing over time but the overall means by group were not different. An interaction effect was significant. Both EMDR and imagery group means decreased from pretest to posttest, but the EMDR decreased more than the imagery. This pattern of findings is similar to the heart rate directional findings. This would lend support to the above mentioned "reliving" effect of the EMDR. The effect sizes are moderate in both instances. The imagery group brought up the upsetting swimming event but then listened to a recorded imagery tape. Their arousal level may not have been as elevated as the EMDR group because they did not "relive" the event.

Three means to measure momentary anxiety were used; state anxiety, SUDS and heart rate. Two measures were cognitive self report and one physiological (3, 13). The three measures indicated group differences among the groups. The anxiety scale was given to all three groups and indicated the EMDR group reported a greater decrease in anxiety over the no treatment group, but was not significantly different than the imagery group. The heart rate and SUDS measures were assessed on the EMDR and imagery groups. The pattern of the results was similar for both measures with the total mean scores for the two groups not differing. But the EMDR group evidenced greater decreases in anxiety measures (heart rate & SUDS) than the imagery. The initial higher scores for the EMDR group may have been secondary to the greater initial arousal level induced by the procedure. The EMDR group evidenced a decrease in heart rate while the imagery group remained essentially unchanged. The SUDS revealed a decrease in the SUDS score by both groups.

All three groups participated in two 100 yard freestyle time trials. There were no main effects for time or group, nor interaction effects. The between group effects was close to significant. The imagery group and the EMDR's mean score difference did not differ, nor was there a great change from pretest to posttest score, but the no treatment group's mean and change was different compared to the EMDR group, with the EMDR group exhibiting a decrease. It may be that both EMDR and imagery resulted in a processing of the traumatic swimming event but that because EMDR evokes a "reliving" of the experience it allowed greater reprocessing than the no treatment (27).

This "reliving" is also supported by the VoC scale results. This cognitive self report component is the measure of the cognitive reprocessing of the traumatic event, represented by dysfunctional information that is physiologically stored. By reliving and reprocessing the dysfunctional information, the participant can access, transform and adopt a more coping schema (27). The EMDR group evidenced a greater change in cognitive adoption of a coping belief regarding the traumatic event. This direction parallels the anxiety measures pattern. Shapiro (27) contends that traumatic incidences may result in dysfunctional "stored memories" and that they can be manifested by all elements of the event; images, physical sensations, taste, smell, sound, affect and cognition. When unresolved traumas are stimulated the person not only sees what occurred but may also reexperience the affect and physical sensations. Maintenance of disturbing elements, such as physical sensations, may be due to inappropriate storage in nondeclarative systems (30). The cognitive aspect was measured by the VoC scale and this revealed that the EMDR adopted a more coping response as a result of the procedure compared to the imagery group. This is supported by the Hanin's (11) Individual Zone Of Optimal Functioning responses to anxiety (IZOF) hypothesis, which states when athletes described their worse sport experience emotions of anger, anxiety and sadness were associated. Graham & Hanton (9) extended this research line regarding positive and negative anxiety and individual differences. It is not that negative emotions are always counterproductive to performance (11), but in this particular study the experience was traumatic and was described as such by the athletes in
cognitive and emotional terms. This line of reasoning that deleterious performance, results when high cognitive anxiety is accompanied by high levels of physiological arousal (Hysteresis) (13, 14, 15).

Conclusions
This study was intended as an exploratory study to ascertain if EMDR is a viable procedure to use with athletes who have experienced a traumatic swimming experience. It was a pilot study to ascertain if EMDR would help the athletes to overcome the negative anxiety and cognitions thus improving their swimming performance. The EMDR group mean time was significantly faster than the no treatment condition in the one hundred yard freestyle. The swimmers were all competitive swimmers but of varying degrees of ability. The construct of anxiety was examined in relationship to performance. Anxiety was measured by the State-Trait Anxiety Scale, heart rate, Subjective units of distress and a cognitive coping statement scale. The relationship between anxiety and performance has received much attention in sport literature and in research studies. Imagery has been used to reduce anxiety and the imagery group served as a comparison group for the anxiety reduction variable. A literature review of imagery use in sport, according to Martin et al revealed most of the studies have examined the use of cognitive specific imagery for enhancing performance (11). The authors concluded that the results indicated that imagery does facilitate performance in specific skills imagined. This was the technique used in the third session for the imagery group. The first two imagery sessions focused on a relaxing scene, while the last imagery session involved the participant's imagined the perfect or ideal swim performance. In this study it was not found that the EMDR group differed from the imagery group as expected.

This study via the EMDR procedure attempted to decrease negative cognitions and the concomitant physiological arousal associated with the “worse swimming experience” by desensitizing the experience and reprocessing it into a more coping cognitive belief.

Applications
This study served to break ground into a new area of study for anxiety reduction and cognitive reprocessing with the procedure of EMDR. The rationale for the more general state-trait measure was because of the exploratory nature of this study. The study is at its infancy in the area of anxiety study for athletic performance with EMDR. The results of this study are encouraging, indicating that it is a potentially valuable technique to aid swimmers to process upsetting competitive experiences into more self-efficacious cognitions.

EMDR might be useful if a swimmer has experienced an accident swimming competitively or performed an embarrassing act at competition, resulting in disqualification. EMDR may be helpful to resolve this negative cognitive set.

A swimmer who has experienced one of the above may approach the next competition with negative thoughts and anxiety concerning the upcoming competition or with a mental picture of the prior catastrophic event. This combination of negative cognitive and physiological anxiety may adversely affect the performance. If the swimmer had EMDR to desensitize the anxiety and reprocess the event into a more constructive coping thought, this may allow him/her to approach the competition with coping thoughts. EMDR might also be used as an alternative to imagery for swimmers to visualize the “perfect swimming performance” for skill enhancement.

Limitations
Limitations of this study include that participants began the study with various levels of swimming and competitive experience. Participants were not randomly chosen but were part of a convenience sample. Level of noise in the rooms where the treatment was conducted and time of day or event varied. Because there were three sites, different pools were used and one group used two different pools for their practices. The 100 yard time trial was not conducted at an actual competition, but performed by the coaches at practice, which could affect motivation.

References
The Influence of a Compressive Laminar Flow Body Suit for Use in Competitive Swimming

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Abstract

The purpose of this investigation was to examine the efficacy of body suits designed to improve laminar flow thereby reducing body drag during swimming. Eight male collegiate swimmers performed three different tests: (1) platform drops in a streamlined position; (2) passive drag at a constant velocity; (3) 365.8-meter constant velocity swim after which physiological variables were measured. Velocity through the water was greater during body suit trials following platform drops (p=0.002). Mean passive drag was decreased in the body suit trials (11.25 ± 3.05 kg versus 10.93 ± 3.35 kg; p=0.12). The 365.8-meter swim showed a reduction in VO₂ (5.09 ± 0.65 L*min⁻¹ versus 4.92 ± 0.61 L*min⁻¹; p=0.11) in body suit trials. Blood lactate was not different (p = 0.88) between suits following the 365.8-meter swim. TYR® Aquapel™ suits resulted in an increased velocity during water descent following platform drops (suggesting a reduction in drag), and reduced passive drag during a passive winch pull (both of approximately 2% at 2m/s). There was a reduction in VO₂ when the participants wore the TYR® Aquapel™ suit. The conclusion of this investigation was that the use of a compressive fitting laminar flow body suit could improve performance.

Index Terms: Swimwear, Performance, Clothing, Drag

Introduction

In order to increase swim velocity, an athlete’s primary obstacle is the increase in drag encountered as he/she moves faster through the water. Body suits designed to reduce drag were popular in the 2000 Olympic swimming events. This is understandable when one considers that 0.13 seconds separated the first and fourth place finishers in the men’s 50-meter free-style, while 0.53 seconds separated first and eighth place (1). A very small reduction in drag could mean the difference between winning a gold medal and finishing last in the finals. Manufacturers claim in advertising pamphlets that suits’ drag reducing properties can help to reduce a swimmers drag by as much as 7.5%. Based on the 2000 Olympic freestyle swimming results, if the eighth place swimmer had a reduction in drag of 7.5%, an improvement suggested by swimsuit manufacturers, he would have finished approximately 0.1 second before the winner.

To date only two studies have examined the impact of the new style of swimming body suits. Toussaint, et al (2002) (8) found no statistical difference in active drag using the measure of active drag (MAD) system for the Speedo® Fastskin™ body suit. In 2003, Roberts, Kamel, Hendrick, McLean, and Sharp (5) also reported no statistical benefit when wearing Speedo® Fastskin™ during sub-maximal free-style swimming. Speedo® Fastskin™ suits are designed to improve performance by reducing drag through the coating on the swimsuit, whereas TYR® Aquapel™ suits are designed to reduce drag as a result of the laminar flow stitching (Figure 1). Laminar flow stitching is intended to improve the movement of water around the body resulting in a reduction in drag. Studies investigating neoprene suits were not included in this review as they are illegal in competition due to their buoyancy.

This study will compare the influence of drag while swimming in a traditional swimming brief as compared to a
laminar flow TYR® Aquapel™ body suit (Figure 1) under three experimental conditions: 1) platform drops in a streamlined position; 2) passive drag of a swimmer while being pulled through the water with a winch; and 3) physiological measures following a 365.8-meter free-style pool swim.

Methodology

Participants:

Eight sprint swimmers, competing in events shorter than 200 meters, were recruited from a nationally ranked Division I men's collegiate team. The high caliber collegiate athletes, many of whom were All-Americans, shared a combined total of 34 top ten Southeastern Conference (SEC) Championship event finishes, 11 SEC event titles, two SEC records, 20 top 10 NCAA Championship event finishes, three NCAA event titles, and one NCAA event record. All testing occurred during the competitive swim season but at separate times from practice. Prior to testing, the participants read and signed a University approved informed consent that was reviewed by the Institutional Human Participants Review Board.

Data were not collected on two participants for the 365.8-meter swims because they moved away prior to the end of the study. Participants were not recruited to replace the individuals due to the time constraints of the competitive swim season and suit costs.

Participant Measures:

Each participant's height was measured to the nearest 0.5 centimeter. Weight was determined to the nearest 0.05 kilogram. Each participant's body fat was estimated using the seven site equation and both three site equations identified in the ACSM Guidelines by an ACSM's Health Fitness Instructor certified researcher (2). Body fat percentage was estimated by averaging the values calculated from the three methods.

Platform Drops:

Participants were required to perform eight platform drops for familiarization, after which the participants performed eight trials for both the traditional suit and the body suit from increasing heights of 1, 3, and 5-meters. Each participant performed a total of 24 drops from each platform (familiarization, traditional, and body) for a total of 72 drops. The participants held a full breath and maintained it while stepping off the platform in a streamlined position (erect position, arms extended directly over head, toes plantar-flexed). Participants maintained the held breath and streamlined position until they reached the bottom of the pool. The participants' velocities at water surface contact were calculated using the following equation:

\[ v_2^2 = v_1^2 + 2(\alpha)(d) \]  
(Equation 1)
Where 'v' represents velocity, 'a' represents gravitational acceleration (9.8 m/s²) and 'd' represents platform height (1, 3, or 5-meters).

A velocity at surface contact curve was calculated using Equation 1 using initial heights. Each entry from the same height was assumed to have the same velocity at water contact. Drops performed from the 1-meter platform resulted in a velocity at surface contact of 4.43 m/s, the 3-meter platform was 7.57 m/s, and the 5-meter platform was 9.9 m/s as determined from Equation 1.

Platform drops were recorded with a JVC model digital camera, with a lens speed set at 60 Hz, through an underwater viewing window located in the 4.88-meter deep diving well of the University's aquatics center. Underwater descents were recorded within the video camera's viewing window.

Analysis just below the surface was not possible due to water disturbance as the swimmer entered the pool. Therefore, the film analysis began when the participant's feet reached 1.83 meters (6-feet) below the surface and continued another 1.83 meters. The toes of the right foot were used as the point of reference during pool descent. The participants' data were graphed using an x-y graph in Microsoft Excel™. A linear equation was derived using the Excel™ computer program. The linear equation gave the initial velocity at 1.83 meters below the surface (y-intercept) and deceleration (slope). The participants' four best entries, identified as the most vertical paths (highest velocities) from each trial were then analyzed.

**Passive Drag Winch Pulls:**

Participants held on to a line attached to an Interface (Nashville, TN) SM250™ force transducer (sampling rate, 100Hz) that was attached to a Power Reel™ Swim Training Device (Mansfield, OH). Prior to passive winch pull trials researchers tested reliability of the towing velocity of the winch pull device. No significant difference was found in velocity between or within subjects during multiple winch pulls. The participants were pulled, while maintaining a streamlined position at a speed set to 2 m/s. The resistive force graph demonstrated an initial peak followed by a plateau phase. The plateau phase represented the constant velocity pull from the 5-10-meter mark during the winch pull trials.

Participants were randomly assigned between suits for a total of 10 trials (five with a traditional suit and five with a body suit). Trials consisted of the swimmer being pulled 15-meters (five to reach constant velocity, and 10 to measure drag) while maintaining a streamlined position. The forces measured by the force transducer during the passive drag were graphed and analyzed. Preliminary testing demonstrated an initial peak in force during the acceleration from 0 m/s to 2 m/s. Once a constant velocity was achieved there was a plateau in the analyzed force. During passive drag testing, the last 3-seconds of each winch pull was used for analysis. This allowed the swimmer to reach constant velocity, this provided constant force measures that could then be compared. Each participant's mean plateau force was then calculated from the data following the removal of their high and low value as determined by a priori study design.

**365.8-meter Freestyle Swims:**

All participants performed one familiarization trial to acclimate the swimmer to the pace, respiratory mask (used for VO₂ analysis), blood sampling, and testing protocol. Once familiarized, participants then performed four randomized 365.8-meter swims, two while wearing a traditional suit, and two while wearing a body suit with 15 minutes between swims. Swimmers maintained a self-selected pace equating to approximately 92% of their best 365.8-meter swim times. Each participant maintained his individually selected pace for all trials. Participants received visual (pace clock) and verbal feedback concerning each lap time during each trial.

At the conclusion of each 365.8-meter swim, participants immediately exited the pool and sat in a chair located at the edge of the pool. Gas and blood collection was initiated within 10 seconds of the completion of the 365.8-meter swim. Exercise VO₂ was estimated using the back extrapolation method as described Di Prampero, Cortili, Mogoni, and Saibene (1976) (3). Concurrent with gas samples, a 20-μL fingerstick blood sample was taken. Lactate concentration was determined using the procedures described by Lowry and Passonneau (1972) (4).

**Statistical Analysis:**

A 2X3X2 repeated measures ANOVA was performed to compare suits (traditional and body suit), platform heights (1, 3, 5-meters), and pool depth (1.83 and 3.66 meters). A Bonferroni post hoc analysis test was performed to determine significant differences among multiple means.

A paired sample t-test was run on the average plateau force to compare suits (traditional and body suit) at a constant speed of 2 m/s (approximate 100 meter freestyle time). Separate analyses were performed for peak resistive force and constant velocity resistive force.

A paired sample t-test was run to compare the VO₂ requirements and lactate concentrations resulting from swimming while wearing a body suit or a traditional suit.

Critical value was set "a priori" at p ≤ 0.15, as recommended by Stevens (2002) (6) for studies with fewer than 20 participants. This more lenient p-value increases the risk of a Type I error. However, this p-value provides analysis of practical significance (differences in performance that may not reach scientific significance). During swim competitions, small changes can make dramatic differences in the finishing place of an individual's performance. For all statistical analyses on swim data, the exact p-value will be reported.
Findings

Descriptive Data

The participants’ descriptive data are presented in Table 1.

Table 1: Swimmers’ Descriptive Data (n = 8)

<table>
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<tr>
<td>Age (Years)</td>
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<tr>
<td>Height (Centimeters)</td>
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<td>Weight (Kilogram)</td>
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<td>Percent Body Fat</td>
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Platform Drop Data

The decrease in velocity caused by drag after entry into the pool from a platform height of 1-meter, 3-meters, and 5-meter platforms are shown in Figure 2, 3, and 4, respectively. There was an increase in velocity for all the trials when wearing the body suit compared to the traditional suit from all platforms heights and at all depths (p = 0.002). The percent change in velocity between suits was calculated for each platform height using Equation 2.

\[
\% \Delta = \frac{(V_{bs} - V_{ts})}{V_{ts}} \quad \text{(Equation 2)}
\]

Where: '%Δ' represents percent change in velocity, 'V_{bs}' represents velocity in the body suit trial, and 'V_{ts}' represents velocity in the traditional suit.

Figure 2: Velocity Changes with a 1-meter Platform Drop (n = 8)

(Traditional Suit velocity change equation \( y = 0.3x^2 - 0.24x + 4.43 \)

Body Suit velocity change equation \( y = 0.01x^2 - 0.13x + 4.43 \))

Figure 3: Velocity Changes with a 3-meter Platform Drop (n=8)

(Typical Suit velocity change equation \( y = 0.08x^3 + 0.70x^2 + 7.57 \)

Body Suit velocity change equation \( y = 0.03x^3 + 0.38x^2 - 1.56x + 7.58 \))

Figure 4: Velocity Changes with a 5-meter Platform Drop (n = 8)

(Typical Suit velocity change equation \( y = -0.12x^3 + 1.12x^2 - 3.48x + 9.90 \)

Body Suit velocity change equation \( y = -0.06x^3 + 0.73x^2 - 2.74x + 9.91 \))

The percent change was calculated to allow one to estimate the influence of drag throughout a range of swimming velocities. The velocity of the swimmers at 1.83-meters was significantly greater than the velocity of the swimmers at 3.66-meters (p < 0.001). The differences observed in the velocity of the swimmers with the two suits at the two depths
were calculated. Since the entry velocity, 1.83-meter velocity and 3.66-meter velocity were known, velocities at similar depths could be compared. A line of best fit predicted the percentage of velocity increases that could be expected when wearing a TYR® Aquapel™ suits compared to the traditional suit. The line of best-fit equation was:

\[ y = -0.0409x^2 + 0.995x - 0.0648 \]  
(Equation 3)

Where “x” represents the initial velocity and “y” represents the percent change in velocity 3.66-meters beneath the surface (r = 0.994).

**Passive Drag Force Data**

Average mean drag force (determined by averaging the forces in the plateau) was 11.25 ± 3.05 kg for the traditional suit trials and 10.93 ± 3.35 kg for the body suit trials (p = 0.12).

**365.8-meter Freestyle Swim Data**

Average time for the swimmers (n=6) to complete the 365.8-meter swim was 4.28 ± 0.04 minutes for the traditional suit trials and 4.28 ± 0.08 minutes for the body suit trials. Oxygen consumption (VO₂) and lactate values are presented in Table 2. There was not a difference in the time of each swim (p = 0.81), or lactate concentrations (p = 0.88) when wearing a body suit as compared with a traditional suit. However, the swimmers experienced a reduction in VO₂ when wearing the body suit (p = 0.11) during the free-style swim.

**Table 2: 365.8-meter Swim Physiological Measures (n = 6)**

<table>
<thead>
<tr>
<th></th>
<th>Traditional Suit ± SD</th>
<th>Body Suit ± SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ (l/min)</td>
<td>5.09±0.65</td>
<td>4.92±0.61</td>
<td>0.11</td>
</tr>
<tr>
<td>Blood Lactate (mmol)</td>
<td>14.21±1.92</td>
<td>14.17±2.30</td>
<td>0.88</td>
</tr>
</tbody>
</table>

**Discussion**

The purpose of this investigation was to determine the efficacy of a TYR® Aquapel™ body suit at reducing the drag and physiological measures of competitive swimmers. The swimmers experienced an increase in velocity when wearing the body suit compared to the traditional suit from all heights at all depths when performing the platform drop trials (p = 0.002). A decrease was also seen in the mean drag force when pulling the swimmers through the water at a constant velocity (p = 0.12). As the water density, entry velocity in platform drops, drag velocity during winch pull, and the swimmers surface area were unchanged, the only reason for these changes is a decrease in the drag coefficient.

Van der Vaart and colleagues (1987) (9) suggest that active drag (MAD—system) and passive drag (passively towed) result in values of similar magnitude, suggesting that active and passive drag measures would demonstrate similar changes in drag with velocity changes. These similar changes would suggest that passive drag would be a good predictor of actual swimming performance.

**Figure 5: Expected Velocity Percent Changes Seen When Wearing a Body Suit Compared to When Wearing Traditional Suit**

The rate of deceleration was influenced by the initial velocity, the participant's body surface area, and the drag created by the suit. Figure 5 shows the percent change that would be expected when wearing the body suit at varying velocities. Percent change at a velocity of 0.00 m/s was considered 0%, the average change in velocity for all swimmers when wearing the body suit compared to the traditional suit at varying initial velocities of 4.43 m/s (from the 1-meter platform), 7.57 m/s (from the 3-meter platform) and 9.9 m/s (from the 5-meter platform). A line of best fit was then calculated to estimate the percent change one might expect at other velocities. These percent differences, as indicated by this graph, would provide a time and place improvement in competition when wearing a body suit.

Passive drag (assessed by measuring the mean drag force of the swimmers when pulled by a winch in a streamlined position) demonstrated a reduction when wearing the body suit compared to the traditional suit. The mean passive drag force allowed us to isolate the changes experienced due to suit wear without the influence of stroke mechanics.

Even though both the platform drop and the winch pull demonstrated a reduction in passive drag (approximately 2%) our findings do not support the claims of the swimsuit company. Based on flume data, swimsuit manufacturers have reported in their advertising pamphlets there to be between a
6% and a 7.5% reduction in drag at normal swimming velocities. 

Body suit wear reduced drag. If a swimmer maintained a constant swim velocity, the swimmer would experience a reduction in energy expenditure. The swim times for the 365.8-meter swim trials for the swimmers participating in this study were not different (Traditional 4.28 ± 0.04 and Body suit 4.28 ± 0.08 min). Since the VO₂ decreased for the swimmers when wearing the body suit, the swimmers would be able to swim faster at any given energy expenditure.

**Applications**

Swim suit manufacturers are attempting to reduce drag and improve performance by altering swim wear in various ways (laminar flow stitching, texture, compression, coatings). The present study was performed on suits designed to reduce drag by improving laminar flow.

The results of this study showed approximately a 2% (at 2 m/s) reduction in drag when being passively pulled or using the prediction equation to predict the change with the platform drop data. The approximate 2% reduction in drag that is suggested by this data could have a major impact on the final place finish at a competition. As velocity increases, drag increases at approximately the squared rate of the increases in velocity (7). Using this estimation, a 2% reduction in drag could lead to a increase in velocity of approximately 1.5%. As stated previously, during the 2000 Summer Olympics the 50-meter freestyle final was won in 21.98 seconds while the non-medaling fourth place swimmer finished in 22.11 seconds; a separation of only 0.13 seconds (1). This margin of victory represents only a 0.5% difference in time. Between first and last place there was a 2.4% difference in time. Using the estimated improvement in swimming velocity that could occur with the use of a laminar flow body suit, the sixth place finisher in the 50-meter final could have won the final by 0.04 seconds if he were to use the body suit while the others used a traditional suit.

Using Equation 3 an estimated percentage change in drag can be calculated for an individual changing from a traditional swim suit to a laminar flow body suit. Greater swim velocities will result in increased water resistance caused by increased drag which will be compounded over the duration of the race.

Swimmer's velocities during water entry and underwater push-off in flip turns are greater than average race velocity and the reductions in drag experienced during flip turns may accumulate to give a performance advantage.

The use of a laminar flow body suit in the 365.8-meter freestyle swim led to a reduction in the oxygen cost (energy expenditure) needed to swim at the same velocity. For the same energy expenditure a swimmer wearing a laminar flow body suit would be able to swim at a greater velocity.

In conclusion, the TYR Aquapel™ body suits in these trials demonstrated a reduction in drag (2% at 2.0 m/s; p = 0.002 platform drops, p = 0.12 winch pulls) and a reduction in VO₂ (p = 0.11), which would improve the time and place of swimmers in competition. Using the prediction equation (Equation 3) there would be an approximate one second reduction in the time of an elite swimmer in a 50 meter freestyle race when wearing the body suit at sprint velocity. Using the same equation, there would be an approximate 23 second reduction in time of an elite swimmer in the 1500 meter freestyle when wearing the body suit at distance race velocity. The small changes in drag experienced when using a body suit do result in changes in race velocity that may change the time and place of the swimmers. In contrast to the use of drag suits for resistance training purposes, the laminar flow body suit reduces drag for performance.

**References**

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Figure 3: Velocity Changes with a 3-meter Platform Drop

Figure 4: Velocity Changes with a 5-meter Platform Drop

Table 2: 365.8-meter Swim Physiological Measures

Figure 5: Expected Velocity Percent Changes Seen When Wearing a Body Suit Compared to When Wearing Traditional Suit
The Relationship Between Dry-Land Power Measures and Tumble Turn Velocity in Elite Swimmers

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Abstract

Dry-land resistance training is intended to increase the force and power output of the muscles specific to swimming performance. In terms of turning ability in the pool, leg power is thought to be important. The purpose of this study was to determine if leg power during a jump squat, countermovement jump and a vertical jump would be significantly correlated with tumble turn ability, and whether these jumps effectively discriminate between those swimmers with faster and slower turning ability. The tumble turn velocity (V2-4 m, V4-6 m, V6-8 m and V8-10 m) of 67 male swimmers from the Australian Institute of Sport Elite Development Squad was assessed using video analysis and then compared with the leg power measures. All the independent variables were significantly related (P < 0.05) to initial turn velocity (V2-4 m), but the correlations could only be described as low to moderate (r = 0.28-0.41). No anthropometric or power measures were significantly related to tumble turn velocity at V6-8 m and V8-10 m. Significantly greater squat jump power at 30 kg (8.4%), countermovement jump height (8.8%), vertical jump height (9.0%) and velocity at take-off (7.2%) were observed for the faster swimmers when compared at V2-4 m. However, significant between-group differences were no longer evident after three metres. It is possible that the exercises used in this study lacked specificity, or that tumble turn technique has greater importance than leg power.

Index Terms: Leg power, freestyle, biomechanics

Introduction

A swimmer's overall performance is most simply reflected in the time taken to complete a race. This time can be subdivided into starting, stroking and turning (7). In terms of turning, it has been reported that freestyle turns comprise 20.5% of the total race time in a 50 m race and 33% of events longer than 200 yards in a short course pool (19). Blanksby et al. (4) and Cossor et al. (6) have reported significant correlations with total event times, and both 2.5 m (r = 0.72 to 0.85) and 5 m (r = 0.90 to 0.97) round trip times (RTTs). In addition, Blanksby et al. (4) found that the fastest and slowest freestyle swimmers differed significantly between the 50 m time and these two measures of turning ability (RTT). Chow et al. (5) found average velocity after the turn to correlate significantly with event time (r = -0.73 to -0.82) and order of finish (r = -0.71 to -0.86) in the 800 m and 1500 m, and male and female, freestyle finals at the 1982 Commonwealth Games.

In terms of turn kinetics, swimmers with faster times have demonstrated significantly higher peak forces (4), greater mean impulses (17) and reduced wall contact times (5, 17). Takahashi et al. (17) also reported that the knee joint was at about 120o of flexion when peak force was observed during
the push off phase of the tumble turn. These researchers also stated that peak force during the vertical jump was observed at a similar range of motion (120-140°). Hence, it has been suggested that coaches implement leg strength and power programmes to increase peak force and to decrease the time to achieve peak force (4).

If this were so, it would be beneficial to develop a land-based training programme that translates into optimal jumping technique. As the turn involves the legs making contact with the wall by flexing and then powerfully extending (a stretch-shorten cycle—SSC), it might be expected that exercises which improved the SSC or rebound ability of the leg muscles would be best suited for improving turn ability. Plyometric exercises such as the vertical jump or jump squat would seem suitable for this purpose. However, such a relationship should not be assumed automatically as small changes in posture, muscle contraction type, range of motion and velocity of muscle contraction could result in limited transference of dry-land training strength improvements to improved swimming performance. Prior to prescribing dry-land training, it might be preferable to determine whether identifiable movements are correlated with the desired performance and whether those movements can discriminate between athletes performing that task (1). Therefore, it was hypothesised that leg power, as assessed via a jump squat, countermovement jump and vertical jump would significantly correlate to tumble turn ability; and that these jump scores would effectively differentiate swimmers with faster and slower turning abilities. The information gained from the above approach would assist in clarifying the efficiency of dry-land training prescriptions for swimmers.

**Methods**

**Subjects**

The group consisted of 67 male (age 17.4 ± 0.5 yr, height 185.5 ± 6.5 cm, mass 80.8 ± 7.8 kg) swimmers from the Australian Institute of Sport Elite Development Squad. Subjects provided written consent for testing as part of their scholarship arrangements with the Australian Institute of Sport. Subjects were informed that they could withdraw from the study at any time without prejudice.

**Equipment**

**Modified Smith Machine (Plyopower)**

A modified Smith Machine (Plyometric Power Systems, Noreach, Lismore, Australia) was used to assess power output during the loaded jump squats. It also allowed subjects to perform the movements in a ballistic manner, meaning the load could be thrown at the end of the concentric phase. Details outlining the modifications of the Smith Machine can be found in Newton et al. (12).

**Vertec**

A portable vertical jump measurement system (Yardstick, Swift Performance Equipment, Lismore, Australia) was set up on a flat surface according to the guidelines in the manufacturer's manual.

**Linear encoder**

A linear encoder (Ergotest Technology, Norway) was attached to the Plyopower Smith machine bar with the encoder giving one pulse approximately every 0.075 cm of load displacement. After every 10 ms (100 Hz), the total counts of pulses were read and displacement was calculated. These data were relayed to a computer-based data acquisition and analysis program.

**Force Platform**

A portable force platform (Quattro Jump, Kistler Instrument Corporation, Amherst, New York) was used for the jump assessment. The force plate was calibrated before testing and secured to the floor according to the specifications outlined in the manufacturer’s manual.

**Camera Equipment**

Video data were collected using Panasonic Industrial Colour CCD Camera WV-KS152. All cameras capture at 25 Hz (or 50 fields per second). A similar frame rate of 25 Hz has been used extensively in the kinematic analysis of swimming. Video of each subject’s tumble turn during the first ten metres from the wall was acquired in a single session. Each subject was videoed a total of three times from which mean velocities during four sections (2–4 m, 4–6 m, 6–8 m and 8–10 m) were calculated.

The cameras were positioned with the focal axis of the lens perpendicular to the plane of motion of the swimmer. In order to reduce perspective error, which Barlett (3) refers to as "the apparent discrepancy in length between two objects of equal length, such as the left and right limbs, when one limb is closer to the camera than the other," a camera to subject distance of 5 metres was used during data collection. Parallax error, which is an error that can occur if the reading is not read in line with the level of the liquid, was minimised by setting the camera height as close to water height as possible. Markers were placed on the side of the pool at 2m, 4m, 6m, 8m and 10 m. Each swimmer had a magnetic marker placed on their head with a white circle drawn in the centre (diameter of approximately 2 cm) using reflective ink. A frame-by-frame analysis of the video was used to identify the point at which the head marker crossed the poolside markers. Times were recorded and used to calculate the velocities over each of the four distances.
Assessment Procedures

Subjects were assessed on two separate occasions. The first session was for the land based tests and the second session was in the pool. The dry-land session involved assessment of leg power using a variety of jumping techniques, which were similar to those jumps used in their dry-land training sessions. The jumps were: 1) a squat jump which measured concentric-only leg power; 2) a countermovement jump which measured leg power without the contribution of the arms; and, 3) a vertical jump which measured leg power with the contribution of the arms. Prior to dry-land testing, each subject completed a thorough warm-up involving 10 minutes of stationary cycling and dynamic stretching of the muscles being used in the test. Jump squat power at loads of 20 kg and 30 kg was assessed using the modified Smith machine. Subjects were instructed to jump with the bar as “fast and high” as possible from a stationary position, standardized at a knee angle of 120° using the mechanical stoppers of the Smith machine. Countermovement jump height and velocity at take-off were recorded from the force platform. Each subject started with both feet on the force platform with the palms of their hands on the hips and was instructed to sink to a knee angle of 120° as quickly as possible. The subject then jumped high as possible in the ensuing concentric phase. At take-off subjects were instructed to leave the force platform with the knees and ankles extended and land in a similarly extended position (22). Vertical jump height was measured using a Vertec (Yardstick, Swift Performance Equipment, Lismore, Australia). Subjects were instructed to sink to a 120° knee angle as quickly as possible and then jump as high as possible to displace the Vertec at the maximum height with the dominant hand. For all jump techniques, subjects performed three trials, which were averaged for analysis. Any jumps that were not executed using the protocol outlined above were not recorded, and an additional jump was performed.

The second session was used to measure freestyle turn velocities in the pool. Prior to the swim assessment, each subject underwent a warm-up of 200 m freestyle swimming with a minimum of two turns at 50 m intervals. Then, three turns of 15 m in and 15 m out were carried out at maximum velocity and these were averaged for analysis. Subjects were encouraged to use their normal tumble turn technique for each trial so analysis was limited by variations in time spent under water.

Data Analysis

The power variables recorded in this study were calculated from the mass-displacement characteristics of the linear encoder attached to the Plyopower Smith machine bar. From the displacement data received via the linear encoder, velocity was calculated at every 10 ms (velocity = displacement/10 ms). Force (F) was calculated according to the formula:

\[ F = m \times g + m \times a \]

where \( m \) = mass of the bar in kilograms, \( g \) = gravity (9.81 m/s²), and \( a \) = average acceleration of the system in metres per second squared. The acceleration was calculated by dividing the change in velocity over the concentric phase of the movement by half of the time in the air, and power was calculated as the product of force and velocity. Mean power output was calculated over the concentric phase only.

Countermovement jump height was calculated from the flight time according to the method of Komi and Bosco (9). This calculation assumes that the time the centre of mass is falling is equal to one-half of the time in the air. Therefore, the body position at take-off and landing must be the same. However, if the body’s centre of gravity lands at a lower level than that at take-off, the jump height is overestimated. Jump height (JHt) in metres was calculated using the formula:

\[ JHt = g \times (air)^2 \times 2-3 \]

where \( air \) = time in the air in seconds and \( g \) = gravity (9.81 m/s²). Komi and Bosco (9) have reported errors of less than 3% when results were compared with those using high speed cinematography. Aragon-Vargas (2) evaluated four vertical jump tests and concluded that the Komi and Bosco (9) test was a relatively simple method to obtain valid and reliable measurements. The time from take-off to landing was used to estimate the vertical take-off velocity (v) according to the formula:

\[ v = g \times air \times 2-1 \]

Vertical jump height from the Vertec, was calculated as height reached at peak of upward jump—the standing height. Standing height was recorded for each subject with the upper back against a wall and feet plantar flexed to ensure accurate standing height measurements.

Statistical Analysis

Means and standard deviations were used to describe all descriptive variables. Pearson correlation coefficients were used to determine relationships between the turn velocity and leg power measures. The subjects were also rank ordered and divided into fast and slow groups based on their initial turn
velocities in an attempt to more clearly identify and differentiate factors contributing to faster tumble turns. Independent sample t-tests were used thereafter to determine if there were significant differences between groups in terms of the anthropometric and power variables. Regression analysis was used to identify those factors (predictor models) that were important in optimizing turn velocities. For this purpose, a forward stepwise multiple regression analysis (SPSS, Inc. Evanston, IL) was used by employing velocity between 2-4 m as the dependent variable. Subject mass and height, as well as the measures of power output, were used as the independent variables. The forward stepwise regression began with no variables in the equation and thereafter entered the most "significant" predictor at the first step and continued to add or delete variables until none "significantly" improved the fit. Minimum tolerances for entry into the model and alpha-to-enter/remove were set at 0.01 and 0.15, respectively. From this analysis, the best single and double predictor statistical models of turn velocity were derived. Regression diagnostics were used to examine normality, variance, collinearity, outlier effects, leverage and influence. A 0.05 level of significance was adopted for all statistical analysis.

**Findings**

The anthropometric, velocity and leg power measures for the swimmers that participated in this study can be observed in Table 1. A 32.6% decrease in velocity was noted over the 10 m distance under investigation. The use of the arms in the vertical jump resulted in a 13.7% (7.6 cm) increase in jump height when compared with the countermovement technique in which the subjects kept their hands on their hips during the jump.

The correlations between the velocity measures and the independent variables are detailed in Table 2. All the independent variables were significantly related (P < 0.05) to initial turn velocity (V2-4 m), but the correlations could only be described as low to moderate (r = 0.28 to 0.41). As distance increased from initial push-off, velocity decreased, as did the number of variables significantly related to velocity. No anthropometric, velocity or power measures were significantly related to tumble turn velocity at V6-8 and V8-10 m.

The fastest and slowest swimmers were compared to determine if any of the variables were significantly different between groups (see Table 3). Turn velocity was no longer significantly different between the two groups after six metres. Significantly greater squat jump power at 30 kg (8.4%), countermovement jump height (8.8%), vertical jump height (9.0%) and velocity at take-off (7.2%) were observed for the faster swimmers. The two groups did not differ significantly in terms of their mass and height.

The best single predictor of initial turn velocity was vertical jump height. This variable accounted for 19.0% of the variance associated with turn velocity (see Table 4). The introduction of body mass to the statistical model improved the common variance by 11.0% above that of vertical jump height alone. That is, the best two-predictor model of initial turn velocity was vertical jump height and body mass (R² = 30.0%).

**Table 1:** Anthropometric, velocity and leg power measures for male swimmers.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>185</td>
<td>6.51</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>80.7</td>
<td>7.82</td>
</tr>
<tr>
<td>V2-4 m (m.s⁻¹)</td>
<td>5.56</td>
<td>0.37</td>
</tr>
<tr>
<td>V4-6 (m.s⁻¹)</td>
<td>4.06</td>
<td>0.29</td>
</tr>
<tr>
<td>V6-8 m (m.s⁻¹)</td>
<td>3.94</td>
<td>0.47</td>
</tr>
<tr>
<td>V8-10 m (m.s⁻¹)</td>
<td>3.75</td>
<td>0.5</td>
</tr>
<tr>
<td>SJ20 (W)</td>
<td>235.3</td>
<td>28.8</td>
</tr>
<tr>
<td>SJ30 (W)</td>
<td>319</td>
<td>51.4</td>
</tr>
<tr>
<td>VJ (cm)</td>
<td>55.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Jht (cm)</td>
<td>47.9</td>
<td>6.5</td>
</tr>
<tr>
<td>VATO (m.s⁻¹)</td>
<td>2.73</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**Key:** V = average velocity between the designated distances; SJ20—squat jump power with 20kg load; SJ30—squat jump power with 30kg load; JHT—countermovement jump height; VJ—vertical jump height; VATO—velocity at take-off.

**Discussion**

A large training volume in the pool and dry-land resistance training characterizes modern swim training. The dry-land portion is intended to increase the force and power output of the muscles specific to swimming. Most of the previous research has investigated the effects of upper body dry-land training on swim performance (4, 8, 10, 11, 14, 15, 16, 18). Very little research has investigated the effects of lower body training on swim performance and even less on tumble turn velocity. Cossor et al. (6) investigated the effects of a 20-week plyometric training programme on freestyle tumble turn velocity of adolescent swimmers. They found equal benefits were derived from normal practice time in the water or from land based plyometric exercises. However, the exercises used in their plyometric programme were not detailed and the subjects were very young (11.7 ± 1.16 yrs) and relatively untrained. Hence, this study sought to determine whether reasonably simulated jumping exercises on land related to tumble turn velocity in elite swimmers. If this was so, dry-land training which was specific to tumble turn push-offs might transfer the land based force and power enhancement into the swim turn. The results of this study offer insight into how the selected dry-land jumping exercises are related to tumble turn velocity.
Table 2: Pearson correlation coefficients (r) and P-values between anthropometric and power variables, and turn velocity for male swimmers.

<table>
<thead>
<tr>
<th></th>
<th>V2-4 m r (P-value)</th>
<th>V4-6 m r (P-value)</th>
<th>V6-8 m r (P-value)</th>
<th>V8-10 m r (P-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>0.28 (0.03)</td>
<td>0.05 (0.66)</td>
<td>0.22 (0.11)</td>
<td>0.16 (0.22)</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>0.41 (0.00)</td>
<td>0.13 (0.28)</td>
<td>0.08 (0.50)</td>
<td>0.15 (0.23)</td>
</tr>
<tr>
<td>SJ20 (W)</td>
<td>0.29 (0.01)</td>
<td>0.27 (0.02)</td>
<td>-0.14 (0.26)</td>
<td>-0.02 (0.88)</td>
</tr>
<tr>
<td>SJ30 (W)</td>
<td>0.36 (0.00)</td>
<td>0.27 (0.03)</td>
<td>-0.08 (0.52)</td>
<td>0.08 (0.52)</td>
</tr>
<tr>
<td>JHT (cm)</td>
<td>0.40 (0.00)</td>
<td>0.27 (0.02)</td>
<td>-0.08 (0.53)</td>
<td>-0.14 (0.26)</td>
</tr>
<tr>
<td>VJ (cm)</td>
<td>0.33 (0.00)</td>
<td>0.33 (0.00)</td>
<td>-0.13 (0.28)</td>
<td>-0.18 (0.15)</td>
</tr>
<tr>
<td>VATO (m.s-1)</td>
<td>0.38 (0.00)</td>
<td>0.26 (0.03)</td>
<td>-0.09 (0.45)</td>
<td>-0.18 (0.15)</td>
</tr>
</tbody>
</table>

Key: V = average velocity between the designated distances; SJ20 — squat jump power with 20kg load; SJ30 — squat jump power with 30kg load; JHT — countermovement jump height; VJ vertical jump height; VATO — velocity at take-off.

Table 3: Male swimmers sorted by swim velocity (2-4 m) into two groups (fast vs slow with T-test and P values)

<table>
<thead>
<tr>
<th></th>
<th>Fast Mean(SD)</th>
<th>Slow Mean(SD)</th>
<th>T-Test (P-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2-4 m (m.s-1)</td>
<td>5.8 (0.2)</td>
<td>5.2 (0.2)</td>
<td>10.46 (0.00)*</td>
</tr>
<tr>
<td>V4-6 m (m.s-1)</td>
<td>4.1 (0.2)</td>
<td>4.0 (0.2)</td>
<td>2.37 (0.02)*</td>
</tr>
<tr>
<td>V6-8 m (m.s-1)</td>
<td>3.9 (0.4)</td>
<td>3.9 (0.5)</td>
<td>0.40 (0.69)</td>
</tr>
<tr>
<td>V8-10 m (m.s-1)</td>
<td>3.7 (0.4)</td>
<td>3.7 (0.5)</td>
<td>0.31 (0.76)</td>
</tr>
<tr>
<td>SJ20 (W)</td>
<td>242.9 (29.4)</td>
<td>230.3 (26.4)</td>
<td>1.78 (0.08)</td>
</tr>
<tr>
<td>SJ30 (W)</td>
<td>334.5 (52.6)</td>
<td>306.5 (46.0)</td>
<td>2.24 (0.03)*</td>
</tr>
<tr>
<td>JHT (cm)</td>
<td>50.2 (7.05)</td>
<td>45.8 (5.2)</td>
<td>2.88 (0.01)*</td>
</tr>
<tr>
<td>VJ (cm)</td>
<td>58.4 (8.6)</td>
<td>53.2 (7.4)</td>
<td>2.61 (0.01)*</td>
</tr>
<tr>
<td>VATO (m.s-1)</td>
<td>2.8 (0.2)</td>
<td>2.6 (0.1)</td>
<td>2.61 (0.01)*</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>82.3 (8.2)</td>
<td>79.6 (7.2)</td>
<td>1.34 (0.18)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>186.5 (5.9)</td>
<td>184.6 (6.9)</td>
<td>1.09 (0.27)</td>
</tr>
</tbody>
</table>

Key: V = average velocity between the designated distances; SJ20 — squat jump power with 20kg load; SJ30 — squat jump power with 30kg load; JHT — countermovement jump height; VJ vertical jump height; VATO — velocity at take-off.

Table 4: Stepwise regression for males for explaining V2-4 m.

<table>
<thead>
<tr>
<th>Males</th>
<th>r</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Predictor VJ</td>
<td>0.43</td>
<td>0.19</td>
</tr>
<tr>
<td>Two Predictors VJ, Mass</td>
<td>0.54</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Key: VJ — vertical jump height.

The average velocity after the turn for the swimmers of this study ranged from 3.75 m.s⁻¹ (8-10 m) to 5.56 m.s⁻¹ (2-4 m), which was considerably faster than the average speeds reported in other studies (4, 5, 13). However, differences were expected as various operational definitions have been used in previous research. For example, differences can be attributed to studies such as Chow et al. (5) that used the average speed out from the wall to the completion of the first stroke, or Blanksby et al. (4) who determined the average speed across a distance of 30 cm prior to the commencement of stroking. Other studies have measured the time taken to travel from 3 m to 10 m from the wall as an average speed-out (see 20 for review of distances). Therefore, a direct comparison of the tumble turn velocities in this study with those found in other studies is of minimal value, since present velocities were measured as averages at specific distances from the wall.

Irrespective of these differences, it was found that power output from the loaded jump squats and height from the two vertical jumps (with arms and without arms) were significantly (P < 0.05) related to the average velocity between 2 m and 4 m from the wall. That is, as the velocity of the swimmer is related to the magnitude of the effective propulsive force, higher velocities create greater drag forces thus affecting velocity out (4, 10, 11). However the
correlations were low ($r = 0.29$ to $0.40$) and no longer achieved statistical significance ($P < 0.05$) after six metres. As distance-out from the wall increased, velocity decreased, as did the strength of the relationship between jump power and tumble turn velocity. The swimmers' velocities immediately after the feet leave the wall would seem to depend on other factors more important than leg power. The streamlined position that a swimmer adopts and resultant drag forces could contribute significantly to the performance.

In view of the statements above, the importance of dry-land jump training with the exercises investigated in this study would be moderate. However, perhaps their value is endorsed after analysing the subjects sorted (based on $V2-4$ m) according to the fastest and slowest swimmers. This more clearly identified and differentiated the selected jumps' contributions to faster tumble turns. With the exception of the squat jump at 20 kg ($P = 0.08$), all the other jump measures demonstrated greater significance in the fastest group. This was also evident at $V2-4$ m and $V4-6$ m, but when velocities were examined at $V6-8$ m and $V8-10$ m, no significant between-group differences in leg power were observed. Again, leg power was relatively important to initial velocity but, after traveling 4-6 m, other factors contribute to the velocity off the wall.

These findings suggest that it would be worthwhile to establish a relationship between leg power, initial turn velocity and performance, however such analysis is difficult due to the variety of distances and events that the subjects are involved in. The average velocity out from the wall after the turn (5) and total turn velocity (21) have been found to correlate significantly with event time, thus, the velocity off the wall in the 2m to 4m is important. Interestingly to note is that one subject in this study was the current World champion and Olympic champion in five events. This athlete recorded the highest $130$ power output and vertical jump height, in addition to the second highest velocity at take-off and initial velocity during the turn ($V2-4$ m).

As stated previously, a streamlined transition from a flexed position at the start of push-off to a fully extended position at the end of push-off is necessary also to prevent the production of excessive drag (4, 10, 11). This may explain why the high point of the vertical jump with the body extended was found to be the best single predictor of tumble turn velocity. Such a movement would appear to more closely replicate the movements of a swimming push-off than the other two types of jumps investigated. However, it should be noted that this variable only accounted for $19.0\%$ of the variance associated with turn velocity. When body mass was entered into the model a further $11\%$ of the variance was explained. Though these two variables substantially contribute to explaining the variance associated with initial turn velocity, the amount of unexplained variance ($70\%$) suggests other factors such as technique are of greater importance.

### Applications

Turning performance is an important component of competitive swimming and coaches would benefit by finding exercises to improve the turning skill of their swimmers. Technique training is essential in optimizing turning performance but other supplementary means of improving turn performance are required. The inclusion of dry-land training in the swim programme could be beneficial to improve the propulsive forces of the leg muscles. The authors propose that dry-land jumping exercises might improve the propulsive forces of the legs and benefit turn turn velocity, although there has been limited transference of dry-land training strength improvements to swimming performance (6, 16, 18). The relatively low, but significant ($P < 0.05$) correlations found between jump measures used in this study and swim velocity only accounted for $19\%$ of the variance. This suggests that the exercises lacked some specificity, or the importance of leg power in the tumble turn velocity is overstated. This finding is supported by the only training study that has investigated the effects of plyometric training on tumble turn performance. Cossor et al. (6) reported that 20 weeks of land based plyometric exercise offered no additional benefits compared to normal practice time in the water. It may be that jump type training performed in the horizontal plane on apparatus such as supine squat machines may afford greater improvement and transference to swim turn performance. Conversely, it may be more important to identify those muscles that are important in streamlining and isometrically train those muscles to observe whether improved velocity out from the tumble turn results. More research is needed in this area that adopts a correlational/regression approach to establish the relationship between the variables of interest and tumble turn velocity. Once significant relationships have been established, training studies are needed to confirm whether such exercises do indeed improve swim turn performance.

### Acknowledgements

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### References

Prescription and Regulation of Swimming Intensity

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Abstract

Components of a typical physical training program include frequency, intensity and duration. Frequency (sessions/week) and duration (minutes/session) are easily calculated. However, quantification and regulation of intensity presents the most challenging aspect of training program design. For the coach, two key elements regarding intensity are precision and convenience. Close attention to these factors permits application of the desired training stimulus (precision) with minimal difficulty (convenience). Heart rate (HR), blood lactate concentration ([Lac]) and ratings of perceived exertion (RPE) are standard methods for prescribing and regulating intensity. Each method offers advantages and disadvantages. With greater precision frequently comes less convenience. Also, as a method becomes more user-friendly, precision is often lost. HR, [Lac] and RPE may also be integrated in attempts to identify an acceptable level of precision that is also logistically feasible when training/coaching a group of athletes. In designing training programs, individual responses must also be considered as a given method may be applied by some athletes more effectively than others. Coaches must consider numerous factors when facing the daunting task of providing effective training programs for athletes. This review provides an evaluation of HR, [Lac] and RPE as methods for prescribing and regulating swimming intensity.

Key words: exercise prescription, intensity, training

Introduction

Formulating an appropriate exercise prescription is described by the American College of Sports Medicine (ACSM) as an “art” due to diversity among participant goals and variations in acute physiological and perceptual responses as well as differences in chronic adaptations (1). The primary components specified when designing a training program are frequency, intensity and time/duration. While these components may fluctuate based on the time period within a competitive season, their manipulation may be critical for providing desired stimuli associated with specific phases of training and (for intensity and duration) each individual workout. Frequency and duration are easily monitored as days or sessions per week and minutes per session, respectively. However, intensity regulation is comparatively challenging partially because variables reflecting intensity can demonstrate high inter-individual variability which creates difficulty for the coach or trainer monitoring multiple athletes. Additionally, some intensity measures may be affected by extraneous factors. For example HR response tends to be elevated as a result of overtraining (5,6). Other factors such as nutritional status (21), fitness level (26) and time of day (9) can also be influential. Identifying the ideal method for prescribing and regulating intensity is also difficult due to the lack of precision in some measures and the constraints associated with assessing others.

Research constraints limit the ability of coaches and scientists to isolate the ideal integration of frequency, intensity and duration when designing and implementing a program. Genetics, muscle fiber composition, age, event specialty,
training history, skill and motivation all conceivably affect what might constitute the perfect training program and it would be difficult to concurrently control all potentially influential factors well enough to ascertain a definitive answer. Nonetheless, coaches and athletes generally subscribe to the program they perceive to be most effective based on previous experiences (coaching and/or competitive), scientific principles or a combination of these factors. Regardless of the foundation, in each case the components of the prescription remain (frequency, intensity, duration). Although easily quantified, the ideal frequency and duration of exercise providing adequate training stimulus and sufficient recovery are not well-understood. Never the less, research suggests swimmers comply well with prescribed distance and duration but may be less adept at judging intensity (19). In contrast to duration and frequency, intensity presents a dual challenge with respect to session regulation. That is, intensity is not only difficult to quantify but the ideal intensity for training is not well-understood. Although many questions regarding the design of programs remain unanswered, a review of literature encompassing all components of an exercise prescription is beyond the scope of this paper. Regardless of the training program, the problem of establishing and regulating intensity is an endeavor for coaches and athletes during each training session. The purpose of the current paper is to review and evaluate some methods for prescribing and regulating intensity during acute swimming bouts with special attention to benefits and drawbacks of each approach.

Intensity Prescription and Regulation

The primary workouts comprising a training program may generally be identified according to intensity. Intensity will at least partially dictate duration as these share a negative relationship (increased intensity forces shorter duration). Long slow distance (LSD) training is often preferred for establishing an aerobic base and is characterized by longer duration which necessitates a lower relative intensity. Interval training involves repeated bouts of higher intensity exercise with interspersed recovery periods. Although exercise and recovery durations may be varied, the negative relationship between intensity and duration remains with longer intervals requiring a lower intensity. A third type is “race pace” training. This training simulates the competition in which an athlete participates (for example 1500 meter time trial) typically replicating event distance and intensity. In prompting the desired overload, LSD training generally induces an overload through extended duration while interval training presents an overload by manipulating intensity. Race pace, along with actual competition performance, may provide a gauge of fitness or efficacy of the training program (18).

Heart Rate

Heart rate (HR) is a popular method of measuring as well as prescribing and regulating intensity. Procedurally, “target zones” are established in relation to maximal HR or HR reserve (maximal HR—resting HR). It should be noted that maximal swimming HR is approximately 12 beats/min lower than maximal HR for running (8). Maximal HR can be estimated using various equations with the most popular being (maximal HR = 220 – age). However, even adjusted for type of exercise, estimations carry a large standard deviation (±10 beats/min) (15) and a direct mode-specific measure provides the greatest accuracy. If an estimation equation is utilized or if maximal HR from a treadmill test is known, based on result of DiCarlo et al. (8) the result should be decreased 12 units (prior to prescription) to reflect maximal swimming HR. Accordingly, specific HR zones can be established based on ability, skill and fitness and in consideration of the goals for each workout type. HR zones foster individualization of the prescription with consideration of maximal and resting HR variations. As resting HR changes with improved fitness or after a period of deconditioning (i.e. off season), target zones can be recalculated to compensate. Compared to resting HR, maximal HR changes little with increased or decreased fitness level and there is little need to perform multiple assessments for this variable. However, because resting HR will fluctuate with fitness, periodic re-assessments should occur and target zones should be re-calculated correspondingly. Although reliability data are not available, mean error for palpatting resting HR is 7 beats per minute (16) making this method adequate when more precise options such as electronic monitors are not available.

Advantages to HR are that it is comprehensible and non-invasive. After a prescription is set, periodic assessment during exercise permits athletes to adjust their effort to comply with the defined HR zone. Exercise HR may be evaluated with an electronic HR monitor or pulse palpation at the radial or carotid artery. Electronic monitors are accurate and most are waterproof. However, arm motion associated with swimming may impair a continual HR readout on the receiver which necessitates a pause in exercise to assess HR. Similar to electronic monitors, palpation is not difficult to learn and allows swimmers to self monitor. However, the exercise session must be paused in order to palpate and accuracy of self-palpation is questionable. Data from our lab show mean differences between actual and estimated HR (from palpation) of 13 to 16 beats per minute (during cycling) (16). In that study (16), palpation error was consistent at low (60Watts), moderate (120Watts) and high (175Watts) intensities. Further, error was similar for 6, 10 and 15 second
palpation methods suggesting extending palpation duration does not improve accuracy (16). It should be noted that these values are means and some individuals may accurately palpate. Palpation accuracy can be compared to an electronic monitor for initial validation and with acceptable agreement, confidence in this technique increases.

HR may provide feedback regarding training progression. HR at a given workload or power output tends to decrease with enhanced fitness. In this case the expectation would be a faster average velocity at the same HR or lower HR at a given velocity. This observation should prompt a reevaluation of resting HR and recalculation of target zones if necessary. Conversely, HR response may be elevated as a result of overtraining (5,6) which could theoretically help coaches and athletes identify presence of overtraining syndrome. Continual monitoring of HR by athletes and recording in a training diary can make HR data available to the coach for each session and across each phase of training potentially providing useful information regarding each athlete’s fitness status. Although observing HR trends may appear advantageous, caution should be practiced when attempting to diagnose overtraining based principally on HR as this is a complex phenomenon.

HR as an adjunct to prescribing and regulating intensity is not without problems with a principal drawback of accurately monitoring multiple athletes. However, because it is convenient, non-invasive and easy to apply, it remains an attractive alternative even if precision is lessened.

Blood Lactate Concentration ([La])

Blood lactate is one of the most widely studied metabolites in the field of Exercise Physiology. Although lactate has been extensively studied, it can be difficult to interpret. It is however, often perceived as a critical measure for gauging intensity. Even so, application has not become as broad as might have been anticipated. Literature consistently suggests the lactate response to exercise is superior to other measures in predicting endurance performance success (25). However, there are drawbacks to utilizing [La] for prescribing and regulating exercise intensity.

Various different threshold markers have been identified in the scientific literature. Weltman (25) reviews several lactate-based threshold values. While some thresholds represent diverse techniques for identifying a specific physiological marker, the vast number of studies regarding different threshold values adds confusion when attempting to apply threshold-based measures to training. A selected intensity marker may serve to distinguish between types of workouts with LSD, interval and race pace training completed below, above and at a specific threshold respectively under the assumption that threshold represents the highest intensity that can be sustained for extended period (i.e. “critical velocity”). Accordingly, there exists a “critical velocity” for each athlete.

The athlete who can sustain the highest velocity through an event wins. Previous research suggests critical velocity corresponds well with maximal lactate steady state during swimming (24). This logic drives the notion regarding the utility of [La] assessment and its incorporation in prescribing and regulating intensity.

Because of its association with critical velocity, periodic [La] assessments during a workout theoretically permit a precise reflection of intensity based on the optimum index of sub-maximal intensity (25). This would allow training intensity to be fine-tuned by adjusting effort level as needed to achieve the prescribed [La] permitting coaches assurance that athletes are completing the desired type (LSD, interval, race pace) of workout. Similar to establishing a HR zone, [La] based prescriptions can, and arguably, should be individualized to optimize training intensity per each athlete’s specific needs. Although individualized training tentatively optimizes results, [La] is more sensitive to training-induced changes than other objective measures such as VO2 max (2,14).

High sensitivity in a measure can be both positive and negative in regulating training. Identifying improvements or decrements in fitness becomes easier with a highly sensitive measure. This means [La] may more accurately reflect program effectiveness. However, with the intensity prescription based upon a hypersensitive measure, more frequent re-assessment of the maximal steady state (highest sustainable level of work) may be required to make appropriate adjustments in the prescription and maintain the desired precision. So while a moderate argument can be formulated supporting [La] for gauging intensity, the requirement of multiple measurements hinders practicality. This model of incorporating lactate concentration as the primary measure of intensity leads directly to another potential drawback to using [La]. Where HR assessments can be completed by the athlete, [La] must be assessed by the coach, trainer or another trained individual. Each athlete would therefore be dependent on outside assistance. From a coaching standpoint an inadequate number of personnel could impair [La] use in any situation other than working with two to three athletes simultaneously. Logistically, insufficient coach to athlete ratios during daily training may present a significant limitation to using [La]. Similarly, equipment (cost and supplies) may restrict the use of [La]. Convenient, user-friendly lactate analyzers exist and portability is also not a problem. However, even with economical analyzers, costs for supplies increase directly when performing multiple analyses.

An additional constraint to using [La] centers on hygiene. Blood samples require tissue (skin) damage and collection of body fluids which increases the chance for transmission of blood-borne disease. Carefully following techniques established by professional organizations such as the Occupational Safety and Health Association (OSHA) minimize the
risk for transmission but do add the inconvenience of keeping items such as gloves and eyewear on hand as well as chemicals in anticipation of cleaning spills.

The precision theoretically offered by direct measures of [La] is appealing. However, the obstacles associated with lactate measurement impair feasibility making broad application of such a technique problematic. Indirect measures have been proposed as effective for regulating [La] which would help overcome some of the associated barriers such as collection of numerous blood samples and coach to athlete ratios. This possibility is explored in a later section.

**Ratings of Perceived Exertion (RPE)**

Borg’s RPE scale (3) was originally investigated as a tool for estimation of acute feelings of strain and fatigue. The RPE scale is based on subjective feelings of exertion experienced during exercise. The ACSM (1) supports RPE as an effective gauge of impending fatigue which is particularly useful during graded exercise testing. An alternate use for RPE is the “estimation-production” model. In this procedure, the RPE scale is used as a prescription tool. Intensity is established by prescribing a desired zone of RPE’s similar to HR-based training zones. Specific physiological responses can be identified (i.e. HR zones, desired [La]) and the associated RPE responses (i.e. estimations) become a RPE range defining the training zone. In this model an athlete adjusts intensity to produce prescribed RPE values instead of prescribed HR values. The primary benefit of this model is decreasing the necessity of continual monitoring of more difficult physiological measures (HR, [La]). The principle drawbacks are a sparse body of literature regarding the validity of RPE for swimming exercise and less precision compared to HR or [La].

In addition to convenience, RPE is simple to understand, thereby permitting athletes to self-monitor without assistance. ACSM (1) states only about 10% of individuals have difficulty understanding and using RPE. Unlike HR, where exercise must be briefly disrupted either for palpation or to view HR from an electronic system, RPE is entirely subjective and requires no break in activity. Athletes can continually consider their feelings of exertion relative to the RPE scale and make subsequent adjustments in their effort to achieve the prescribed RPE. Because it is derived from subjective feelings, theoretically, the RPE scale should “self-adjust” for the fatigue associated with overtraining and for added strain as a result of environmental extremes and for changes in fitness level, as each of these alter the physiological responses thought to drive RPE. More research is necessary to verify this however. The RPE scale can be used as an independent tool for prescription. ACSM (1) notes that RPE 12-13 corresponds to 40-60% HR reserve while RPE 14-16 corresponds to 60-85% HR reserve. ACSM (1) also notes that, with respect to the relation of RPE to physiological variables such as HR, significant inter-individual variability exists and consequently encourages individualizing the prescription.

While the ranges presented above obviously lack the precision potentially desired, individualizing a prescription to compensate for variability between athletes could enhance accuracy. Using the RPE scale to prescribe for LSD, race pace and interval workouts is also feasible. Research suggests the lactate threshold occurs at an RPE of 13-14 (12,17). Consequently, utilizing this as a reference, less than RPE 13-14, could be incorporated as a prescription marker for LSD training during which the aim is to maintain a very low lactate concentration. Interval bouts could on the other hand, be described as intensities the athlete is well-aware they can not maintain for extended durations. Intensity for simulated race session can also be established via perceptual means. Given a distance (which is a known factor in competitions), athletes adjust their pace to a level they feel permits them to complete the distance in the fastest time without incurring debilitating fatigue. In each of the latter two scenarios (intervals and race simulation), RPE responses can be paired with such feelings of exertion for establishing intensity. Utilizing RPE for prescribing race pace and interval training is not well-understood and is not likely not without problems. Particularly, variability among athletes may hinder broad application.

Recent research has examined the RPE scale as a gauge of the difficulty of the entire exercise bout (vs. at any given point in time) (7,10). Known as the “session RPE”, early studies suggest this method shows promise. However investigations using swimming as the exercise mode have not been published. In general, RPE provides a convenient method for quantifying intensity while requiring no measure of physiological responses. Used alone, however, precision in the exercise prescription may be impaired. The greatest potential for RPE may be its utilization for indirectly regulating HR or [La]. Using a combination of subjective and objective methods may enhance convenience with less sacrifice in precision. This integration of methods is discussed in the next section.

**Integration of Regulatory Models**

As described above, HR, [La] and RPE may be used independently for prescription and regulation of swimming intensity. The methods should not however, be considered mutually exclusive. Because each method has advantages and disadvantages, and because athletes may respond differently to each, employing a combination of the methods may provide the most efficacious approach. Some suggestions for integrating modes are discussed below.

**RPE-HR Regulation**

The preference for a physiological determinant of exercise intensity is easily understood considering the potential ambiguity of the psychophysical model (RPE) previously
discussed. However, constraints surrounding continual HR monitoring may prompt utilization of RPE as an option for indirectly regulating HR. This procedure requires identifying the desired intensity based on HR response, and identifying the RPE response(s) associated with this intensity or range of intensities. An RPE-based prescription should theoretically permit the athlete to produce the desired physiological response by self-adjusting effort to adhere to a prescribed RPE or RPE range. Trials in which an athlete adjusts intensity based on RPE are known as “production” trials (a prescribed RPE is produced). Production trials typically follow trials in which a subject approximates their feeling of exertion at various intensities. These are known as “estimation” trials (perceptions of exertion are estimated). Burke and Keenan (4) and Ueda and Kurokawa (23) determined RPE was a useful indicator of swimming intensity while Kolyn and colleagues (13) found HR was not correlated with RPE. These studies based conclusions on RPE estimations only and did not examine the RPE as a prescription tool. Green et al (11) found HR production accuracy at higher (RPE 16) but not lower (RPE 12) intensities when using the estimation-production model. While this study supported the use of RPE as a prescriptive tool, initial RPE estimation trials were completed on a cycle ergometer prior to swimming trials where swimmers were asked to produce a given RPE. A more sport-specific approach would be to anchor RPE responses to specific HR responses during swimming and then follow these estimation trials with RPE-based swimming prescriptions. While this model is logical, to date, no studies directly examining such a prescription technique have been published. It would be relatively simple to validate this method by calculating a HR-based prescription and having each swimmer perform a validation trial. This could involve athletes swimming at varying levels of effort while recording HR and concurrent RPE estimations. After establishing the RPE-HR association, RPE could be used to regulate HR. Another option would be to calculate a HR-based prescription and prescribe various RPE values to determine correspondence with HR. Again, desired HR responses could be paired with specific RPE values which subsequently identify the intensity range. Once validated against HR, RPE could serve as the sole moderator of intensity. This should reduce the constraints of continually monitoring HR but increase the precision associated with RPE.

The drawbacks of monitoring HR remain, even when indirect monitoring through RPE permits accurate HR production. Periodic adjustments may be required as fitness improves or declines and new HR zones are established. The advantage could be that RPE, due to its perceptual basis, may adjust for these variations. RPE (vs. HR) does appear to respond differently than HR to variations in water temperature (22). RPE deserves more attention regarding its use in regulation of swimming HR and the factors that may disrupt any potential relationship.

**Indirect Blood Lactate Regulation**

As previously discussed, [La] arguably provides the optimum criterion measure of intensity with various constraints simultaneously making it the most difficult measure to monitor. Similar to prescribing RPE to indirectly regulate HR, a [La]-based prescription can be indirectly regulated using RPE or HR. This technique requires measuring [La] initially and pairing specific RPE responses or HR values associated with desired [La] values. Afterwards, specifically prescribed RPE responses or HR values should result in effort levels that generate the desired [La]. Subsequently the individualized RPE or HR values that correspond to LSD, interval and race pace can be prescribed with moderate confidence without absolute necessity of [La] measurements.

Previous research supports this estimation-production technique for regulating [La] during running (20). Weltman (25) also suggests RPE shows promise in regulating [La], although he points out the most accurate method is direct [La] assessments. Although theoretically sound, little research has directly investigated monitoring [La] indirectly with RPE specifically during swimming. Regardless of scientific research, the concern among coaches and trainers is assisting athletes in effectively regulating intensity. The methods that are most effective may vary among individual athletes. Therefore, regardless of whether research refutes or supports this method, validation trials in specific athletes should be viewed as the true gauge of effectiveness. Periodic re-assessments can also refine prescriptions and allow for adjustments as a result of fitness changes. Re-assessments also can be used as auxiliary evaluations of progression and program effectiveness.

**Application and Future Research**

In a typical exercise prescription, frequency, intensity and duration are prescribed. Intensity represents the most difficult variable to regulate. A critical evaluation of various methods available for regulating swimming intensity reveals positive and negative characteristics for each. A summary of the most widely-utilized methods and associated positive and negative aspects is included in Table 1. Coaches should consider various factors when selecting a method for prescribing and regulating intensity. The desired degree of precision is important. Early season, RPE may suffice as LSD dominates training for enhancement of aerobic base. The decision may then be to shift to periodic [La] assessments with indirect assessment by HR or RPE as the season progresses and then change to frequent [La] assessments during more critical phases of training.
Measurement limitations may also dictate the chosen method. In general, using measures with greater precision (i.e. [La]) result in greater costs, more complications and more personnel involvement. Other methods such as HR and RPE are far more convenient but forfeit accuracy, which in some cases may be acceptable. Possibly integrating various methods offers the most attractive option as precision is sacrificed in order to devise a prescription/regulation method that is reasonably convenient. Coaches deciding to employ indirect monitoring of [La] using RPE or HR, or HR using RPE should perform validation trials with each athlete to ensure precision as opposed to broad application of a given range of HR’s or RPE responses. A validation trial involves each athlete performing swim tests of varying intensities while the association between [La] and HR, [La] and RPE, HR and RPE or HR and [La] are identified.

Individualizing intensity prescriptions for each athlete is paramount. Regardless of the chosen method(s), athletes vary in their physiological and perceptual responses to exercise and any prescription should account for these inter-individual variations. Failure to consider individual responses results in each athlete following virtually the same prescription regardless of their event, current fitness, phase of training relative to competition, etc. Although catering to each athlete as an individual is more time-consuming, the quality of training per athlete should be enhanced resulting in the ultimate ambition of optimum performance. Individualization not only involves establishing appropriate frequency, intensity and duration, but also entails employing the best intensity regulatory method for each athlete. It is plausible that, within a group of swimmers some may be able to accurately regulate [La] using HR while others are more precise using RPE. Identifying and employing the most effective methods for prescribing and regulating intensity is essential to high quality training. Individualization in this way also encourages closer overall monitoring of training progress and permits adjustments in each athlete’s training program.

Many measurements that are simple when made in the laboratory during cycling or running become difficult during swimming. Therefore, comparatively less research has focused on effective intensity regulation during swimming. Future investigations should attempt to provide more definitive answers to the utility of various methods of prescribing and regulating swimming intensity and the adherence of swimmers to various methodologies. Perceived exertion and other methods show potential utility in training, however, more rigorous investigations are needed to validate this application.

References
Energetic, Kinematic, and Freestyle Performance Characteristics of Male Swimmers

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Abstract

The purpose of this investigation was to examine the relationship among propelling efficiency (Ep), velocity at a blood lactate (Bla) of 4 mM ($V_{4,0mm}$), swimming performance, and kinematic parameters from a swim field test in trained male swimmers varying in freestyle talent level. Swimmers (n=14) completed a series of submaximal and one maximal swim in which expired air was collected (open circuit spirometry). Bla was determined for each swim, $V_{4,0mm}$ assessed, and Ep was estimated based on work by Toussaint et al. (15,16,18). Swimmers were categorized into a fast and slow group based on 91.4 m in 365.8 m performance swims. They also performed a 7 x 45.7 m freestyle field test at progressively faster velocities while stroke rate (SR) was monitored. Interpolation was employed to determine SR at velocities of 1.5 and 1.7 m s⁻¹. Pearson r correlation coefficients were significant (p<0.05) for $V_{4,0mm}$ versus Ep (0.89), velocity for the 91.4 m swim (0.65), and velocity for the 365.8m swim (0.82). The faster swimmers had a greater $V_{4,0mm}$ (1.16±0.04 m s⁻¹ vs 1.01±0.13 m s⁻¹) and estimated Ep (48±5 vs 37±12%) compared to the slower group (p<0.05). The r values for SR at 1.5 and 1.7 m s⁻¹ versus Ep, 91.4 m and 365.8 m performance swims were all > - 0.65 (p<0.05). The faster swimmers were able to partition more of the total mechanical power output into overcoming drag forces (useful power) and less into giving masses of water a kinetic energy change (wasted power). This finding supports the faster group's ability to sustain a greater $V_{4,0mm}$ and lower SR during the field test. Furthermore, the 7 x 45.7 m kinematic field test appears to be a time efficient diagnostic tool to discriminate between talent levels and perhaps monitor changes in skill throughout a training season.

Introduction

Investigators have employed both invasive and non-invasive measurements to better understand the metabolic and mechanical features that distinguish a talented from a less talented swimmer, and to monitor training responses during a swimming season. Such measurements include oxygen consumption to determine swimming economy or peak aerobic power (2,6,9), blood lactate testing to determine aerobic and anaerobic thresholds (8,9,11,20), and a combination of metabolic and mechanical assessments to determine freestyle propelling efficiency (14,15,16,17). Propelling efficiency, the ratio of power to overcome drag (useful power) to total mechanical power generated by the swimmer, has received considerable attention in the literature. Toussaint et al. have reported propelling efficiency values ranging from 46 to 77% for top competitive swimmers and values below 46% for less competitive swimmers (14,15). These findings suggest that talented swimmers are able to sustain a greater swimming velocity for a given rate of energy expenditure. Despite the many published investigations on propelling efficiency, we were not able to find any systematic studies relating propelling efficiency to other physiological measurements such as peak aerobic power, relative physiological load, and blood lactate response.

Less technical field tests that use critical swimming speed to estimate threshold pace for endurance training (9, 20), or a 3000 meter evenly-paced maximal swim, known as a T-3000 meter test (9), have also been employed for determining an individual's anaerobic threshold pace. Such tests can be utilized to provide the coach and swimmer with quantitative
feedback regarding how the body is responding and adapting to swim training. Although testing provides useful information, coaches and athletes may be reluctant to give up training time or alter training schedules to participate in sometimes complex and time-consuming assessments.

One field test assesses stroke mechanics by having a swimmer perform a series of short freestyle swims (7 x 50 m) on a two-minute cycle, at progressively faster speeds (13). The attractive aspect of this test is that it requires relatively little time to administer, basic equipment (i.e., stopwatch), and simple kinematic computations. For each 50 m swim, kinematic parameters such as stroke rate and distance covered per stroke cycle are computed and the relationship among stroke rate, distance covered per stroke cycle, and the time required to complete each 50 meter swim are plotted. For example, data presentation may involve producing a figure with stroke rate (strokes min⁻¹) on the vertical axis and time (sec) for each progressively faster 50 meter swim plotted on the horizontal axis. Coaches can then examine the relationship between stroke rate and time. The authors contend that your more skilled swimmers are able to maintain a more favorable stroke rate profile from the slowest to the fastest swim. This is evidenced by a more skilled swimmer being able to prolong that point on the curve at which there is a non-linear rise in stroke rate as swimming speed increases.

It has also been reported that talented swimmers are able to maintain a lower stroking frequency (a greater stroke length) at a given swimming velocity (3,9,12), suggesting a better feel for the water, which has been associated with a greater propelling efficiency (16). A skilled swimmer, therefore, might have a stroke rate versus swimming speed curve which is displaced downward and to the right compared to a less skilled counterpart. It is clear that the 7 x 50 meter field test described above may be used to distinguish among talent levels and could be employed to monitor any changes in stroking mechanics throughout a training season. Despite a sound rationale for its use in the field, we have found no studies that have compared results from the 7 x 50 meter kinematic field test to other established laboratory assessments of swimming ability.

The purpose of this investigation was to examine the relationship among peak aerobic power, estimated propelling efficiency, velocity at a blood lactate concentration of 4 mM, and swimming performance among swimmers differing in freestyle performance talent level. Furthermore, stroke rate at several given velocities was determined from individual stroke rate versus speed curves derived from a 7 x 45.7 m freestyle field test. It was hypothesized that a faster freestyle performer would be characterized by a lower stroke rate at a given submaximal velocity, and that this favorable kinematic characteristic would track well with other laboratory-based measurements of swimming ability.

Methods

Experimental Design

Trained male swimmers were categorized into a faster (n=7) and slower (n=7) group based on 91.4 and 365.8 m freestyle performance times (Table 1). The first testing session was conducted during the morning hours following an overnight fast. It involved anthropometric, a series of submaximal and one maximal freestyle swim in which metabolic response (open circuit spirometry) and stroke rate were measured, and blood lactate testing for determination of individual blood lactate profiles. Propelling efficiency was estimated, as described below, at a common metabolic power value of 1000 Watts (~2.8 l O₂ min⁻¹; ~ 66% VO₂ peak). The latter metabolic power value was used by Toussaint et al. (14) to compare propelling efficiency among trained swimmers. The second testing session was performed approximately one week later and consisted of assessing stroke rate during a series of 45.7 m freestyle swims performed at increasingly faster velocities. Following the field test, subjects performed 91.4 and 365.8 m freestyle performance swims for time.

Subjects

Fourteen men volunteered to participate in this investigation. Twelve swam for Central Washington University, one swam for a local club, one volunteer was a competitive triathlete who trained year-round. This study was approved by Central Washington University Human Subject Review Board and all subjects read and signed a human subject consent form. Physical characteristics are presented in Table 1.

Anthropometry

Height and body mass were measured, Lange calipers were used at seven sites to estimate body density, and percent adipose tissue was estimated using the Siri equation (7). Lean body mass was calculated by subtracting fat mass from total body mass.

Swimming economy

Submaximal

Subject's were fitted with a Polar heart rate monitor and then performed a warmup in the water. As part of the standard warmup, subjects were familiarized with a snorkel used for the collection of expiratory air. The snorkel's inspiratory and expiratory tubes were in-line with one another, similar to a snorkel apparatus described by Toussaint (17). Five or six submaximal, discontinuous 274.3 m freestyle swimming efforts while wearing a small pull buoy between the thighs were performed. Consequently, the rate of energy expenditure was not reflective of whole body freestyle swimming but rather of the mechanical work performed by the upper
extremities only. Measuring the rate of energy expenditure associated only with the upper extremities was necessary in order to apply the method of Toussaint et al. (14, 15, 16, 17, 18) for the estimation of freestyle propelling efficiency.

Submaximal swim efforts were completed with open turns, with each swim performed at increasingly faster velocities. To assist in maintaining the goal pace, subjects were provided with verbal feedback about splits while their heads were out of the water during the open turns. Swimming velocity ranged from approximately 0.8 (swim 1) to 1.3 m s⁻¹ (swim 5 or 6). Prior to each swim, subjects were reminded to maintain an even pace, to execute quick open turns, and to resume swimming immediately following the turn. The first 91.4 m of each swim was completed without the snorkel. Following the first 91.4 m, the participant stopped (~20 sec) and was fitted with the snorkel. The snorkel was connected to an expiratory air collection apparatus (4) which one of the investigators held as the participant completed the final 182.8 m.

Expiratory gases were collected approximately over approximately the final 65 m into a meteorological bag (~50-80 sec collections) and analyzed for percent oxygen and carbon dioxide with Vacu-Med oxygen (Model 17620) and carbon dioxide analyzers (Model 17630). The analyzers were calibrated prior to each swimming economy test and checked with known gases throughout the testing session. The volume of each expiratory gas sample was measured with a calibrated dry gas meter. The time taken to complete the final 68.6 m was used to compute a representative submaximal velocity. In addition, mid-pool stroke rate was assessed (timed stroke cycles) over the final three lengths of each submaximal swim effort. SR values for the three lengths were averaged to yield a representative stroking frequency (stroke/min). An active rest of approximately five minutes of easy swimming, and stretching in the water was performed between submaximal swims.

Following the last submaximal effort, swimmers rested (light swimming, stretching) for 15 minutes then performed a maximal 274.3 m swim (without pull buoy) for the assessment of whole body peak aerobic power. Subjects were instructed to perform the first 91.4 m of the maximal effort at approximately the same pace as the last submaximal bout. Subjects were stopped (~20 sec) after 91.4 m and fitted with the snorkel, then progressively increased the effort with the last 91.4 m covered as fast as possible. Expiratory gases were collected over approximately the last 65 m. Peak velocity was defined as the time required to swim the final 68.6 m.

Finger sticks were performed immediately following each submaximal swim and at 1, 3, 5 and 7 minutes post-maximal swim for the determination of peak blood lactate (YSI 1500 Sport Blood Lactate Analyzer). Stored Polar heart rate data for the submaximal and maximal swims were downloaded following the testing session. Heart rates associated with the final 68.6 m of submaximal swimming were averaged to yield a representative heart rate value. The greatest recorded one-minute heart rate during the maximal swim was used to represent maximal heart rate. Rating of perceived exertion was assessed immediately following the maximal swim using Borg's 6-20 scale (1).

**Estimation of propelling efficiency**

The total mechanical power generated by a swimmer during an evenly paced freestyle swim is equal to the power to overcome drag (useful power; Pd) plus the power wasted in moving masses of water backwards (16). Unlike land-based activities, where the athlete pushes off against an immovable surface to accelerate forward, a swimmer pushes off against masses of water. As a result, part of the total mechanical power is lost in giving water a motion or kinetic energy change (Pke) (16). Propelling efficiency is the ratio of power to overcome drag to the total mechanical power generated by the swimmer and is described mathematically by the following formula (15):

\[ \text{Ep} \, (\%) = \left( \frac{\text{Pd} \cdot \text{Po}^{-1}}{100} \right) \]  

where,

\[ \text{Ep} = \text{propelling efficiency} \]
\[ \text{Po} = \text{total mechanical power output} \quad \text{Po} = \text{Pd} + \text{Pke} \]
\[ \text{Pd} = \text{power to overcome drag} \]

The procedure for assessing propelling efficiency involves the use of elaborate equipment and is time consuming (15). Consequently, for this study, freestyle propelling efficiency was calculated by estimating selected components of equation one. The total mechanical power output was estimated utilizing the following equation:

\[ \text{Po} = e_m \cdot \text{Peq} \]  

where,

\[ \text{Po} = \text{total mechanical power output} \]
\[ e_m = \text{mechanical efficiency (constant, 9%)} \]
\[ \text{Peq} = \text{power equivalence for oxygen uptake (1 O}_2 \text{ min}^{-1}) \]

Mechanical efficiency (e_m), also known as gross efficiency, is the ratio of total mechanical power output to the rate of energy expenditure and is expressed as a percentage. Toussaint et al. have reported similar mechanical efficiency values (~9%) during freestyle swimming among trained male swimmers (16). This suggests that 9% of the metabolic power generated by the swimmer is converted into the total mechanical power to swim freestyle. The power equivalence for oxygen uptake (Peq,) reflects the rate of energy expendi-
ture and is expressed in Watts (joules s\(^{-1}\)). The following formula was used to determine \( P_{eq} \):

\[
P_{eq} = \frac{1}{60} \times 10^3 \times (4.2 \times (4.047 + \text{RER})) \times VO_2
\]

(Eq. 3; (5))

where,

\[
\text{RER} = \text{respiratory exchange ratio}
\]

\[
VO_2 = \text{oxygen uptake in l/min}^{-1}
\]

The power to overcome drag (\( P_d \)) expressed in equation 1 was estimated by using the following equation (15):

\[
P_d = A \times V^3
\]

(Eq. 4)

where,

\[
A = \text{drag factor} = \frac{0.35 \times \text{body mass (kg)} + 2}{\text{swimming velocity cubed}}
\]

The drag factor component of equation 4 has been studied by Toussaint et al. (16,17,18) and represents a constant of proportionality in the mathematical formula describing the relationship between force to overcome drag (\( F_d \)) and swimming velocity squared (\( V^2 \)). \( F_d = A \times V^2 \). The drag factor incorporates the density of water, a drag coefficient and the greatest cross-sectional area of the swimmer, and was estimated using the swimmer’s body mass as reported by Toussaint et al. (18).

Swimming velocity at a common rate of energy expenditure (1000 Watts) was estimated from individual regression equations derived from data collected during the submaximal swim tests and used in equation 4 above. Using this approach allowed for the comparison of propelling efficiency at a common metabolic power between the faster and slower freestyle swimmers, and is reflective of the same method of comparison as described by Toussaint et al. (14).

Swimming performance

Swimming performance was assessed by maximal 91.4 and 365.4 m freestyle time trials from the starting blocks. All subjects were encouraged by the research team to swim as fast as possible.

**Stroke mechanics field test**

The stroke mechanics field test is typically performed in a 50 m pool (13). For this study, however, investigators had access to a 22.8 m pool only. The field test consisted of 7 x 45.7 meters freestyle on a two minute cycle. Prior to engaging in the test, subjects completed a warmup (1000-1500 yd) of mixed swimming, pulling, and kicking with the last portion including several 45.7 m repeats at the initial testing velocity. Testing velocities were determined by predicting the individual’s best 45.7 m swim performed at maximal effort. The first 45.7 m effort was swim about 12 seconds slower than the individual’s predicted best time for the day. Each subsequent repeat was swum approximately two seconds faster than the preceding effort, with the last 45.7 m swim performed at maximal effort. All swims were performed from a push start. The first observed movement was used as the start time, while the hand touch represented the completion of the swim effort.

Stroke rate was determined between the five yard line (between 4.6 and 18.3 m) by using a stopwatch to measure the time to finish four complete stroke cycles for each length. The stopwatch was started as the right hand entered the water (marking the start of the cycle) and stopped as the same hand entered the water to complete the fourth stroke cycle. SR (strokes/min\(^{-1}\)) was calculated by dividing four stroke cycles by the recorded time in seconds (4 cycles x recorded time\(^{s^{-1}}\)) then multiplying this quotient by 60. SR values for the two lengths were averaged to yield a representative SR for the 45.7 m swim.

**Statistics.**

Independent groups t-tests were used to compare between the faster and slower swimmers on selected mechanical and energetic parameters. Simple linear regression was used to determine individual regression equations for submaximal swimming velocity cubed on power equivalence for oxygen, and submaximal stroke rate on swimming velocity. Linear regression was used to study the relationship between performance parameters (91.4 and 365.8 m performance swims) and selected mechanical-energetic parameters.

Blood lactate concentrations were plotted against swimming velocity to establish individual blood lactate profiles, from which velocity at a fixed blood lactate of 4.0 mM (\( V_{4.0} \)) was determined by interpolation. The stroke rate associated with \( V_{4.0} \) (SR \( V_{4.0} \)) was estimated by entering \( V_{4.0} \) as the independent variable into the regression equation for stroke rate on swimming velocity. The distance covered per stroke cycle associated with \( V_{4.0} \) was estimated by dividing \( V_{4.0} \) by SR \( V_{4.0} \). For the 7 x 45.7 m stroke mechanics field test, SR was plotted against swimming velocity. SR at a common swimming velocity of 1.5 and 1.7 m/s\(^{-1}\) was determined for each swimmer using interpolation. Level of significance was set a priori at 0.05.

**Results.**

The faster and slower swim groups were similar in age and lean body mass; however, the faster swimmers were lower in percent adipose tissue (Table 1) (p<0.05). Peak oxygen uptake values did not differ between the faster and slower groups. Peak blood lactate concentration was similar between the faster (10.34±2.57 mM) and slower (9.38±1.74 mM) (p>0.05). Heart rate, respiratory exchange ratio, and rating of perceived exertion for the maximal 274.3 m swim were similar between groups (Table 2).
Table 1. Physical characteristics and freestyle performance results for the faster (n=7) and slower (n=7) swimmers (mean±SD).

<table>
<thead>
<tr>
<th>Talent Level</th>
<th>Age (yr)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>LBM (kg)</th>
<th>AT (%)</th>
<th>91.4 m (m/s)</th>
<th>365.8 m (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster</td>
<td>20.0±2.5</td>
<td>76.4±8.4</td>
<td>183.3±5.8</td>
<td>68.6±4.6</td>
<td>9.5±5.0</td>
<td>1.74±0.07</td>
<td>1.47±0.04</td>
</tr>
<tr>
<td>Slower</td>
<td>20.0±1.9</td>
<td>78.0±10.3</td>
<td>176.1±7.0</td>
<td>66.9±7.4</td>
<td>13.9±3.5</td>
<td>1.62±0.11*</td>
<td>1.28±0.06*</td>
</tr>
</tbody>
</table>

LBM, lean body mass; %AT, percent adipose tissue.
*p<0.05

Table 2. Selected physiological responses during a 274.3 m maximal freestyle swim for the faster (n=7) and slower (n=7) swimmers (mean±SD).

<table>
<thead>
<tr>
<th>Talent Level</th>
<th>VO₂ peak (l/min)</th>
<th>HR (bpm)</th>
<th>RER</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster</td>
<td>4.42±0.40</td>
<td>180±7</td>
<td>1.13±0.06</td>
<td>18.6±0.5</td>
</tr>
<tr>
<td>Slower</td>
<td>4.24±0.50</td>
<td>180±6</td>
<td>1.08±0.08</td>
<td>17.7±1.1</td>
</tr>
</tbody>
</table>

HR, heart rate; RER, respiratory exchange ratio; RPE, rating of perceived exertion, 6-20 Borg Scale (1).

Correlation coefficients (r) for velocity cubed on metabolic power equivalence (Peq.) was greater than 0.97 (p<0.05) for all swimmers. The predicted swimming velocity (with pull buoy) for the faster and slower groups at a common metabolic power equivalence (Peq.) of 1000 Watts was 1.15±0.05 and 1.05±0.09 m/s, respectively (p<0.05). Since a constant swimming mechanical efficiency of 9% was assumed, the estimated total mechanical power (Po) to swim freestyle at a metabolic power output of 1000 Watts was 90 Watts (0.09 X 1000 Watts).

The estimated drag factor (~29 kgm⁻¹ for both groups, Table 3), and predicted swimming velocity at a metabolic power of 1000 Watts, were used to compute the power to overcome drag (Eq. 4). The power to overcome drag was significantly greater for the faster versus the slower swimmers. Consequently, it was estimated that the faster group delivered less mechanical power in giving water a kinetic energy change compared to the slower swimmers (Table 3). At a metabolic power of 1000 Watts, the faster group was found to have a greater estimated propelling efficiency than the slower group.

Swimming velocity at a fixed blood lactate of 4.0 mM was ~13% greater in the faster group compared to the slower group, despite no difference in relative physiological intensity (~67% VO₂ peak) (Table 4). The faster group was able to achieve this greater velocity by maintaining a greater distance per stroke cycle since both groups maintained a similar stroking frequency.

The r values between peak oxygen uptake and performance velocity for the 91.4 and 365.8 m swims was 0.13 and 0.17, respectively, (p>0.05). The r values for the 91.4 and 365.8 m freestyle performance swims versus V₄₀₈₃ was 0.65 and 0.82, respectively (p<0.05) (Figure 1). The r value between propelling efficiency and V₄₀₈₃ was 0.89 (p<0.05) (Figure 2).

Table 3. Estimated drag factor (A), power to overcome drag (Pd), power in giving masses of water a kinetic energy change (Pke), propelling efficiency (Ep), and swimming velocity at a metabolic power of 1000 watts (mean±SD).

<table>
<thead>
<tr>
<th>Talent Level</th>
<th>A (kgm⁻¹)</th>
<th>Pd (Watts)</th>
<th>Pke (Watts)</th>
<th>Ep (%)</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster</td>
<td>28.7±2.9</td>
<td>43.5±4.9*</td>
<td>46.5±4.9*</td>
<td>48.3±5.4*</td>
<td>1.15±0.05*</td>
</tr>
<tr>
<td>Slower</td>
<td>29.3±3.6</td>
<td>33.8±10.7</td>
<td>56.7±10.7</td>
<td>37.1±12.1</td>
<td>1.05±0.09</td>
</tr>
</tbody>
</table>

*p<0.05
Table 4. Relative physiological intensity (%VO₂ peak), swimming velocity (SV), stroke rate (SR) and distance per stroke cycle (DS) at a fixed blood lactate of 4.0 mM for the faster (n=7) and slower (n=7) swimmers (mean±SD).

<table>
<thead>
<tr>
<th>Talent Level</th>
<th>%VO₂ peak</th>
<th>SV (m·s⁻¹)</th>
<th>SR (stk·min⁻¹)</th>
<th>DS (m·stk⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster</td>
<td>67.6±7.0</td>
<td>1.16±0.04*</td>
<td>34.3±3.4</td>
<td>2.05±0.2*</td>
</tr>
<tr>
<td>Slower</td>
<td>66.7±8.3</td>
<td>1.01±0.03</td>
<td>33.2±3.2</td>
<td>1.82±0.1</td>
</tr>
</tbody>
</table>

*p<0.05

Figure 1. Relationship between performance velocity for a 91.4 and 365.8 m freestyle swim versus swimming velocity at a fixed blood lactate of 4.0 mM in trained male swimmers (n=14).

Figure 2. Relationship between estimated propelling efficiency (Ep) and swimming velocity at a fixed blood lactate of 4.0 mM in trained male swimmers (n=14).

For the 7 x 45.7 m stroke mechanics field test, the faster group maintained a lower stroking frequency compared to the slower group (31.2±3.7 vs. 40.2±4.6 stk·min⁻¹) (p<0.05) at a standard swimming velocity of 1.5 m·s⁻¹. At a given velocity of 1.7 m·s⁻¹, the faster group was also found to maintain a lower stroking frequency (41.3±4.9 stk·min⁻¹) compared to the slower group (50.0±4.2 stk·min⁻¹) (p<0.05). The r values between SR at 1.5 m·s⁻¹ versus propelling efficiency, 91.4 and 365.8 m swimming performance were -0.70, -0.73 and -0.79, respectively (p<0.05). Similarly, the r value between SR at 1.7 m·s⁻¹ and the same parameters were -0.77, -0.65 and -0.76 (p<0.05). In addition, SRS at 1.5 and 1.7 m·s⁻¹ were also found to track well with V₄₀ m (r=0.68 and 0.77, respectively, p<0.05).

Swimming velocity for the last 45.7 m swim for the faster (1.86±0.07 m·s⁻¹) and slower groups (1.74±0.09 m·s⁻¹) (p<0.05), was achieved with no difference in SR (53.6±4.3 (faster) and 55.0±4.3 stk·min⁻¹).

Discussion.

This study clearly illustrates that peak aerobic power is not a discriminator of swimming talent level even for a 365.8 m performance swim which requires a significant aerobic energy contribution. VO₂ peak as a poor predictor of swimming performance is especially highlighted when examining individual data. For example, within the faster group, the swimmers with the lowest and highest VO₂ peaks (3.7 and 4.9 l·min⁻¹, ~24% difference) completed the 365.8 m performance swim in approximately the same time, 247 vs. 252 seconds (2% difference), respectively. Other factors which may explain performance differences include one’s ability to minimize resistance to forward motion, effective application of mechanical power, and/or the ability to sustain a high rate of energy release throughout the performance swim. The mechanical and energetic measurements conducted in this investigation highlight that an effective application of propulsive power, or skill, is a key discriminator of performance outcome.

The 7 x 45.7 m stroke mechanics field test employed in this study has been described as a time efficient tool to assess a swimmer’s skill level by evaluating stroke rate over a range of progressively faster swims (13). It has been suggested that a more skilled swimmer is able to prolong that point at which there is a non-linear rise in stroke rate as swimming velocity increases. In this study, we chose to focus on assessing stroke rate at several given velocities. Stroke rates at 1.5 and 1.7 m·s⁻¹ were found to be about 29 and 21% lower in the faster group of swimmers, suggesting a greater distance covered per stroke cycle for the faster group to maintain a given swimming velocity. Provided that swimming velocity is not being compromised with an excessively long stroke length, it makes
good sense that covering a given distance with fewer strokes is suggestive of a swimmer who has better stroke mechanics.

Stroke rate at 1.5 and 1.7 m/s was found to track well with the 91.4 and 365.8 m freestyle performance velocities, lending further support that the field test may be used as a diagnostic tool to assess talent level. Our findings are in agreement with other studies which have illustrated that a more talented swimmer is typically able to cover a greater distance per stroke cycle at a given swimming velocity (3,9,12). Covering a greater distance per stroke cycle at a given velocity may be the result of a more optimal body conformation in the water (better streamlining) and/or simply a more effective application of propulsive power.

Furthermore, the ability to sustain a given velocity with a lower stroking frequency may result in a lower metabolic power output, suggesting better economy. The 7 x 45.7 m stroke mechanics field test, therefore, has both a practical and scientific basis for its use as a tool for assessing swimming mechanics.

The power to overcome drag for the faster and slower groups was ~ 44 and ~ 34 Watts which was reflected in a velocity difference of 0.10 m/s between the faster and slower swimmers (1.15 vs 1.05 m/s). This finding also reflects the greater estimated propelling efficiency achieved by the faster swimmers compared to their slower counterparts. The faster group’s greater estimated propelling efficiency suggests that they were able to apportion more of the total mechanical power output into overcoming drag forces (useful power) and less into giving masses of water a kinetic energy change (wasted power). These findings clearly highlight the importance of mechanical skill as a discriminating factor in freestyle swimming performance.

Although it is realized that there is considerable variability as to the blood lactate concentration associated with the so-called anaerobic threshold (8,11), $V_{\text{O2,ana}}$ has been shown to be a discriminator of swimming talent level (19). We found that $V_{\text{O2,ana}}$ corresponded to 67% VO$_2$ peak (a metabolic power of ~1000 Watts) for both the faster and slower groups. However, the faster group was able to achieve a greater velocity (1.16 vs 1.01 m/s$^2$) for the same relative physiological load. Despite a similar stroking frequency at $V_{\text{vel,ana}}$ = 33-34 stckmin$^{-1}$, the faster swimmers were able to cover a greater distance per stroke cycle (2.05 vs 1.82 mstk$^{-1}$). On a practical note, this implies that the faster swimmers had a better feel for the water, and is in line with our finding of a greater propelling efficiency in the faster group.

**Practical**

It is recognized that the use of a stopwatch during a time trial provides the definitive answer to ascertaining talent level and monitoring performance changes throughout a swimming season. However, this method of monitoring performance provides little insight into the swimmer’s physiological or mechanical profile. Consequently, numerous invasive and non-invasive tests have been employed to assess changes in a swimmer’s skill (technique) and physiological status throughout the training season (2,6,8,9,11,13,15,20). Many of these tests are time consuming and some require specialized equipment. The 7 x 45.7 m field test employed in this study is simple to administer and requires relatively little time to perform. Data (i.e., $SR$ at 1.5 and 1.7 m/s$^2$) derived from the 7 x 45.7 m mechanics field test was found to discriminate between faster and slower freestyle performers. Also, results of this field test were in agreement with other mechanical and energetic measures of talent level. Therefore, the stroke mechanics field test may be ideal for coaches to employ as a means of monitoring their swimmers’ mechanics throughout the training season. Future research is certainly warranted in which the 7 x 45.7 m field test is employed to assess kinematic changes throughout a swim season, and how any changes in either stroke rate and/or distance per stroke track with swimming performance throughout the swim season.

**References**


Swimming Stroke Mechanics: A Biomechanical Viewpoint on the Role of the Hips and Trunk in Swimming

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Introduction

The stroke profile of the competitive swimmer remains somewhat of a paradox. When viewed from above water, 'efficient' swimming by an accomplished athlete looks like smooth, unhurried movement of the arms and legs. From underwater, however, even the most cursory glance tells a different story. Hands and legs, shoulders and hips travel through the water in complex three dimensional patterns of movement that make 'cause and effect' determinations difficult.

One apparently 'current' coaching controversy is the role of the trunk, specifically the hips, as far as contributing to the propulsive forces generated during swimming. Recent coaching publications have emphasized the rotational movements of the hip and trunk during swimming as being desirable, fundamental and important. This controversy, however, is far from current in that discussions of body and hip roll can be documented back as far as the 1930's (3). Although lagging behind coaching discussions, the contention that the hips and hip rotation are responsible for propulsive forces is slowly being addressed in the research world. Does conscious and voluntary rolling of the hips, particularly when swimming the Freestyle (Front Crawl), enhance the swimmer's ability to exert propulsive force (12)? Maybe, or maybe not, much as the early literature on this topic debated. The purposes of this paper are to (1) examine the anatomical and biomechanical factors associated with spine stability as they apply to swimming and (2) consider the implications of emphasizing hip and body roll during front crawl swimming.

The Skeletal Framework for Swimming

In order to examine how the axial skeleton or trunk enables the arms and legs to generate propulsive forces, several fundamental concepts need to be established.

Concept One: Muscles need a stable base of support from which to exert contractile forces.

Skeletal muscles perform multiple functions. Muscle contact. When they do so, they generate and transmit force to external objects and change joint angles. Muscular contraction involves shortening of the muscle, and thus, most muscles cross at least one skeletal joint if not two. Most commonly then, for the muscle to perform its duty, it is necessary to be anchored on at least one end to a relatively stable or immovable platform (bone or set of bones). This stable end is commonly close to the spine, and is referred to as the muscle’s “origin”. This end is also referred to as the “proximal attachment”, in contrast to the opposite end, which is referred to as the “distal attachment” (5,8,18,20). However, this is commonly the case as the proximal attachment point tends to be relatively ‘fixed’ itself by contact to the ground or other external surface. The more powerful the muscular contraction needs to be, the greater the need for the proximal attachment of the muscle to be anchored to some stable base. Only in this way, can the muscle generate a significant force against some object or medium.

An appropriate example of this would be an astronaut who is circling the earth in a zero gravity environment. The astronaut trying to generate force against the floor or wall of the vehicle simply cannot do so unless is tied or tethered to some immovable platform. Pushing against any set object will only cause the untethered astronaut to move in the opposite direction. Because it takes very little force to do so, the astronaut who is floating in space cannot generate resistive forces. Even tightening a loose screw becomes a major problem.

An excellent example of this “bioengineering” is illustrated when the muscles that control movements of the human shoulder are examined (19). Because the primary functions of these muscles are to move the arm, they all have their distal
attachments on the upper arm bone, the Humerus. However, these muscles’ proximal attachments, are located near the center of the body, in two general locations. They attach to the ribs and spine or, they connect to the shoulder girdle, which is comprised of the clavicle and scapula (5, 9). Muscles that apply the most force, the so-called “prime movers” of the shoulder, tend to have their proximal attachments on the ribs and spine. Most of the large muscles important in aquatic locomotion, (front crawl swimming) fall into this category. These are the Pectoralis Major and Latissimus Dorsi muscles.

In contrast, the smaller shoulder muscles, such as the deltooids, and the (in) famous "rotator cuff" muscles, attach to shoulder girdle (5,9). When compared to the Pectoralis and Latissimus muscles, it is clear that they do not have the ability to generate anywhere near the force the larger muscles controlling gross arm movements can. The bottom line in terms of muscular force generation is muscle cross sectional area. In general, bigger the muscle, the greater the force is that it can produce. However, the essential point here is that when muscles contract and generate forces, the more stable the base the better able they are to generate this force specifically when it comes to doing work on the external environment. If there is no stable base, the forces generated are inconsequential. The stable base for the shoulder tends to be the spine and or shoulder girdle.

**Concept Two:** When exerting propulsive movements in swimming, the axial skeleton or “trunk” provides the only available stable base of support.

Spine specialists and physical therapists are very familiar with the concepts of spine stabilization. When dealing with lower back injuries, of which there are many and frequent, patients are taught to stabilize the spine and use it as a stable platform. When they do so, they can effectively move while minimizing pain and further trauma.

To borrow a concept from structural engineering, the trunk, which includes the hips, is viewed as a “semi-rigid cylinder” held in place by “guide wires.” These guide wires are needed to maintain the natural curves in the spine. The muscles located in the front and lateral sides of the trunk are the Rectus Abdominis, Internal and External Obliques, and Transverse Obliques. The muscles located in the back include the major spine extensors, which are the Erector Spinae. Although these muscles function in bending and twisting, they also provide postural stability. This is particularly so when the upper and lower extremities (arms and legs) exert forces, such as during pulling, lifting and carrying (10,15,16).

Therefore, if the muscles of the arms and legs are to be effective in generating propulsive forces while swimming, it would stand to reason that all necessary steps must be taken to maintain the trunk as a stable base of support.

**Essential Point:** Regardless of the three dimensional body position, effective use of the arm and leg muscles for propulsion requires maintaining the trunk in an anatomically stable position relative to the arms and legs.

**Concept Three:** The body can be viewed as a series of linked segments, connected by the skeletal joints. When functioning effectively this linked system can help transmit inertial forces. The forces exerted against the environment and generated by the muscles attached across these links result in motion.

The terms “kinetic chain” or “kinematic chain”, are engineering terms that refers to rigid bodies that are linked together. This term was adopted by the rehabilitation community to describe the cooperative movements of the anatomical segments of the human body. “Closed kinetic chain” activities are defined as those movements that take place with the distal anatomical segment held relatively immobile. “Open kinetic chain” activities are defined as movements where the distal anatomical segment moves freely during the activity, such as during kicking during swimming (10). However, due to their inherent vagueness, these terms are now used sparingly. What has evolved from this is the “Segmental Interaction Principle”. This principle supposes that the potential and contractile energy generated within the various segments can be transferred during the motion between segments (11). Consequently, what is ultimately important is the manner in which each link contributes to the final result. The final results are observable and effective body movements.

When the ‘linked chain’ model is applied to land-based activities, the primary base of support is usually the ground. There exists then, the need to maintain a firm foot-plant with the ground during an effective golf swing. When performing swinging movements with the body, such as during a gymnastics routine, there must be an immovable platform present. The platform is represented by a fixed bar, beam or the ground. A hand, knee, foot or toe must be in contact with this anchor to be able to generate or impede inertia. At any rate, in order to generate maximum muscular external forces asa means to push, pull, kick, or throw an object (or the body itself), some part of the body must be stable, immobilized or anchored. The better anchored at one end of this segmented chain, the more powerful is the force that can be exerted at the other end.

Where does the energy (potential and kinetic energy) of the applied muscular force of the limb originate? It is common to assume that the muscles surrounding the joint are responsible. This is true to a certain extent, but their contribution turns out to be relatively minor. According to the “Segmental Interaction Principle” much of the energy originates from the base of support or anchor. This energy is transferred via the body segments, usually from the proximal to the distal segments (11). Everything there is to know about how this transfer of energy is not known, but if a movement is initiated, for example, while standing on the ground, the energy that is
harnessed comes from the force that pushes against us by the ground. The reaction force supplied by the ground is referred to as "ground reaction force" (GRF) and can be measured by using a force plate (4,7,23).

If GRF is present, then a sequential series of movements takes place, which, for most land-based activities includes the rotation of the hips, trunk, and shoulders. Each successive link will summate to amplify GRF and produce surprisingly powerful movements, such as the swing of a racket or bat. However, in the absence of GRF, when there is no 'firm footing', the energy must originate from some part of the body that is held in a stable position. In most cases, when GRFs are absent, the trunk must take over the role of the ground, or stable platform, from which the linked segmental system can work.

**Essential Point:** A commonly used principle in biomechanics states "proximal stability is needed for distal mobility" (10,11). What this implies is that when a muscular force is generated, in this case at the end of the hand or foot, the requirement is that the other end of the chain, whether the immediate end, or further back along the segments, remains relatively stable. It does not imply or require that it remain immovable. But it is clear that the less stable the proximal end is, the less effective muscular force can be generated at the distal end of the chain. The inertia of the torso is substituted for normal ground reaction forces.

**How does this apply to swimming stroke mechanics?**

When a swimmer is floating in the water, there are only very small forces that effectively represent ground reaction forces. Because water is displaced when a force acts upon it, the resultant ground reaction forces are very limited in magnitude. Without a stable base or without feet firmly planted, the ability to push, pull, or throw any object (or the body) is significantly decreased because the magnitude of the summates forces generated are also limited. This observation should not surprise anyone, especially anyone who has attempted to throw or hit a ball while standing on a slippery floor. One might speculate that bowling on ice might be more visually entertaining and physically challenging than it is on a wooden floor!

**Exerting muscular forces in the water**

A pilot study conducted at our laboratory, was initially designed to examine the biomechanics of water polo throwing techniques. However, it demonstrated what the effects are when GRFs are progressively decreased.

Using high-speed video cameras, a subject was filmed while performing an overhand throwing action using a water polo ball. The subject was first filmed while standing on the ground, and then in progressively deeper water. The final ball throws were made while floating in deep water. The subject making the throw was a member of the women's varsity track & field team who specialized in the javelin throw and therefore familiar with the proper mechanics of throwing.

The data was analyzed using a motion analysis system (Peak Performance Technologies, Denver, CO). The velocities of the ball at the point of release are shown in the graph (Figure 1). The data obtained from the analysis are shown in Table 1.

**Table 1.**

<table>
<thead>
<tr>
<th>Body Position</th>
<th>Velocity (meters/sec.)</th>
<th>Velocity (miles/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing on land—power stance</td>
<td>20.03</td>
<td>44.8</td>
</tr>
<tr>
<td>Standing on land—parallel foot plant</td>
<td>18.17</td>
<td>40.65</td>
</tr>
<tr>
<td>Hip depth</td>
<td>15.56</td>
<td>34.8</td>
</tr>
<tr>
<td>Mid-chest (sternal) depth</td>
<td>16.03</td>
<td>35.8</td>
</tr>
<tr>
<td>Shoulder depth</td>
<td>13.63</td>
<td>30.49</td>
</tr>
<tr>
<td>Suspended in deep water using a buoyancy vest</td>
<td>12.23</td>
<td>27.36</td>
</tr>
</tbody>
</table>

![Figure 1—Comparison of Throwing Velocities while standing on land and at varying depths of water, and when floating in deep water.](image)

As the subject stood in progressively deeper water, changes in GRF had a marked effect on the velocity of release of the ball. The value shows a steady decrease in the velocity of the ball at the point of release. The highest velocity (~20 m/sec) coincide with the most common stance for throwing or hitting actions on land, i.e. standing with one foot placed ahead of the
other. The least ‘anchored’ position occurred when the subject was required to throw the ball while suspended in deep water, supported by a floatation vest. This latter position resulted in the lowest ball velocity (~12 m/sec). The drop in velocity is concluded to be primarily due to the absence of nearly all GRF. The decrease in ball velocity between the “grounded” and “ungrounded” throw was approximately 40%.

This demonstration extends the preliminary discussion of muscular contractions, forces and “anchoring”. In the absence of a “platform”, muscular forces can still be generated through limb movement and muscular work. However, the transfer of this movement energy is limited by a relative lack of proximal stability. The only “base of support” is the muscular and skeletal anchor represented by the trunk. The muscular & axial platform provides the anchor from which muscular forces are initiated. Needless to say, this anatomical platform is less than perfect in comparison to the ground.

The focus on “hip” action in swimming.

It is reasonable to conclude that in the absence of GRF, the hips and lower lumbar region act as stable base against which the muscles of the upper and lower extremities generate forces. The relevant question then, is whether or not it is prudent and appropriate for coaches to prescribe “active” hip rotation as a means to increase the propulsive forces generated at the distal end of the chain?

Let us address this point by asking a series of questions.

Question 1: Can the trunk and hips be held in a fixed position during swimming thus simulating a stable base or anchor on the ground?

The answer is a simple “no”. Evoking fundamental Newtonian physics, “for every reaction there is an equal and opposite reaction” it can be hypothesized that because there is no anchor and there are only trivial ground reaction forces, any forces generated at one end of the chain will cause equivalent forces at the other end. Holding any part of the body in a fixed, relatively immovable position (other than along the primary axis of velocity) is clearly unwarranted if not impossible. Voluntarily contracting the anterior abdominal muscles or unilaterally contracting the posterior trunk muscles with the intent of preventing the rotation of the trunk is useless and will only interfere with necessary resultant bilateral movements of the arms and legs. Perhaps a case in point here: When was the last time one you over heard a swimmer complaining of “exhausted hip rotators” following a competitive event?

Question 2: Is hip rotation ‘voluntary’ and consciously initiated or is it ‘involuntary’ and or only reactionary?

The question is not “how much should we roll” but rather “how much emphasis should coaches place on ‘voluntary’ hip and body rotation?” It is well known that hips “roll” or rather there is rotation around the central axis during crawl swimming. Indeed, the origin of the multicolored ‘panel’ swimsuit stems from Counsilman’s early filming of swimmers in the early 1960s. His wife was asked to sew a contrasting side panel on a standard suit so that he could analyze, quantify and thereby understand the importance of hip and body “roll.”

However, to pursue this specific question, let’s consider a concept which takes into account the difference between actions that are purposefully initiated, and those movements of the body that occur only as a result of movements or counter to those made when exerting propulsive forces with the hands and feet. In other words, we face in this discussion the proverbial “chicken or the egg” conundrum.

Obviously, for fast, proficient swimming, the hands and feet must be coordinated and placed in reasonably well-established patterns during swimming. The muscles that perform these movements are viewed as “initiators” because they have to consciously be activated in order to complete the desired movement. In the freestyle, when the hand is introduced into the water and guided to full extension it is a conscious motion. When the hand “catches the water” and forces are generated against the water, these are voluntary and intended. All of these movements are initiated and or facilitated by a combination of muscles associated with the Shoulder Girdle and Glenohumeral joints. Over time, the movement is learned and remembered. Different parts of the CNS direct and coordinate these movements partially dependent upon how much ‘thinking’ and or how much ‘remembering’ takes place.

In contrast to the movements that are consciously made, there are ‘reactive’ movements of the body that that athletes unconsciously initiate in response to the primary initiated movements. A land-based example of this would be the forward movement of the legs when a volleyball player jumps vertically upwards and returns the ball over the net. Following the principle of “transfer of angular momentum,” the player’s legs must move forward in response to the forward motion of the arms or the athlete will begin to rotate and execute a forward summersault.

Coaches are well aware of this effect and are careful to instruct swimmers not to swing their arms too low and too vigorously over the water during the arm recovery in the crawl stroke. They want their swimmers to minimize lateral trunk and leg motion that occurs in response. Counsilman acutely hypothesized that swimmers with poor shoulder flexibility had to use a wide recovery and because of this tended to swing their buttocks from side to side. Compensation for this required crossing over action of the feet that would counter act the swinging of the hips and allow the center of mass to move with little wiggle.

Any force that is exerted perpendicular to the long axis of the body will have the effect of causing body roll. Therefore, while the “initiators” begin and control arm movement, other parts of the body, particularly the torso, exhibit rotating movements. Ideally, because the joint segments are linked
together, these rotating movements should be confined to the longitudinal axis and take place in the transverse plane.

When we observe the freestyle and backstroke from a "head-on" view, it is clear that this rolling action is an integral part of the stroke. However, it is also evident that when the body is made to roll more that a certain degree, extraneous movements emerge. The argument presented here is that hip roll is "in reaction to" rather than the "initiator of" propulsive forces generated during swimming. This is indirectly related to a general lack of a stable anchor while in the water.

Takaishi in 1935, according to Carlile (3), concluded: "the maximum of rolling is when the power gained by that rolling is applied to the arm movement." This seems to suggest that Takaishi thought power originated from the roll rather than the other way round. Carlile states, however, that later in 1942, Kiputh concluded that "the body should be in a perfectly flat position" and that "there should be no dipping of the shoulders or rolling of the body." Carlile's own view in 1963 was that "roll" is necessary from the perspective of breathing and arm recovery. He states "this type of arm recovery (high elbow)... is not possible unless the body is rolled to some extent around its longitudinal axis." Maglischo's more recent view (13) is that body roll "improves the propulsive forces they (front crawl swimmers) can apply with the stroking arm and it facilitates the recovery of the other arm." This is strikingly similar to the earlier opinions of both Carlile and Counsilman. All of this is being pointed out to illustrate that over the years, many of the greatest coaching minds in swimming routinely discussed and opined upon the importance and or significance of hip and body roll during the crawl stroke.

Question 3: Is it possible to have too much roll and are there recognizable symptoms of excessive hip and trunk rotation?

There are characteristics of the stroke that can be observed from both above and underwater that indicate excessive hip rotation.

1. Increase in the lateral "spread" of the feet.

The most serious consequence of the feet spreading apart is its effect on frontal resistance. We see from Figure 2 that as body roll increases, the degree to which the feet spread apart, increases. To the extent that rolling the hips is accomplished by rolling the torso, the torque required for this rotation must come from the reaction force between the water and either the arms or the legs. Since the arms must move in the preferred pull pattern, it follows that the legs must produce the additional torque for rotation. The axial rotational torque produced by the kick increases with increasing separation of the feet. Therefore, intentionally exaggerating the normal roll of the hips will require the feet to be moved farther apart to accomplish this roll. The consequence of this increase in amplitude of the lower extremity limbs is an increase in frontal surface area.

Frontal resistance is another way to describe the resistance produced by the surface area of an object when a body is moving through a fluid. Any part of the body that that is aligned at right angles to the flow, in this case water, will slow motion down because it contributes to "form drag", which is one of the resistive force that retards the forward progress of a body moving through a fluid (1,8). Swimmers, and for that matter all athletes who have to contend with the retarding force of air or water, go to extraordinary lengths to minimize "form drag".

Therefore, the orientation of the body should be such that the minimum area of the body and/or limbs should be seen when viewed from the front or "head on". Usually, this frontal view is compromised if the body does not remain in a longitudinal orientation and the arms or legs extend out sideways too much, or for too long.

Maglischo (14) puts it pretty directly, "swimmers in the front and back crawl strokes really don't have a choice between rolling and swimming flat, even if flat body positions produce less form drag. Their choice is to roll or wiggle." His opinion is that "if swimmers try to prevent the trunk and hips from rolling up and down in the same direction as the arms, the trunks and legs will swing out to the side."

2. Arm Recovery.

We can agree that a high arm recovery is preferable to one that is takes place low over the water. As mentioned earlier, low arm recoveries invariably result in lateral movements of the torso and legs, particularly if the recovery is made too vigorously. However, conspicuous rolling of the hips is often accompanied by an elevated arm recovery. This is most likely due to the combination of the exaggerated movement of the}

Figure 2. Frontal view of exaggerated body roll in the Freestyle.
torso, including the shoulder complex, and the perception that the "higher the arm recovery the more efficient the stroke".

Summary

We know that trial and experimentation must remain the driving force in the evolution of swimming stroke mechanics. However, although the concept of "body roll" is deeply entrenched in freestyle swimming, a strong case can be made to use caution when recommending conscious or 'over' rotation of the hips when swimming freestyle. Although it may be useful to measure the degrees of body roll in elite swimmers, quantifying this parameter may be only part of the answer. The current anatomical analysis is consistent with Maglischo's view that "because the body is suspended in the water, the up and down movements of the arms exert forces on the torso that cause it to follow in the same direction." The 'egg' appears to be the propulsive forces generated by the swimmer and the 'chicken' would seem to be body roll. For the present, then, voluntary and intentionally exerted body roll—for the express purpose of generating additional propulsive forces seems to run the risk of reducing the ability of the trunk to provide a stable anchor for the propulsive movements of the upper and lower extremities. It may also result in increased drag forces that ultimately retard forward velocity. Statements like "lead with the hips" are not only ambiguous but are scientifically unsound when taken literally.

On a more visible note, it is evident that exaggerated rotations of the body amplifies frontal resistance and by prolonging the duration of each stroke cycle, may interfere with the rhythmic cadence of the stroke. Therefore, it is concluded that while we continue to experiment and push the limits, untested ideas, especially those that cannot be demonstrated in elite performers, should be viewed with healthy skepticism.

References

In Print: Swimming 2004-2005

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References were obtained from Medline and SportDiscus with keyword “swimming” for journal articles and books published in English during 2004 and 2005. 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.

ANTHROPOMETRY


BIOMECHANICS


Thompson, K.G., R. Haljand, and L. Martin. A comparison of selected kinematic variables between races in national to elite male 200 m breaststroke swimmers. JSR 16:6-10, Fall 2004.

CHILDREN


COACHING


Pursley, D. A program designed to produce swimming excellence - what does it look like?. *Am. Swimming* 2004(3):30;33.


DISABLED


ERGOGENIC AIDS


Peyerbrune, M.C., K. Stokes, G.M. Hall, and M.E. Nevill. Effect of creatine supplementation on training for


**GENERAL**


**HYDRODYNAMICS**


**INJURIES**


**MASTERS**


**NUTRITION**


**PHYSIOLOGY**


**PSYCHOLOGY**


Janson, L. Achievement of timing at the highest competitive level: the necessity of a 'driving conviction'. *Athletic Insight: Online J. Sport Psych.* 7(2), Jul 2005.


**SPORTS MEDICINE**


**TEACHING**


**TECHNIQUE**


Colwin, C. Finding the rhythm. *Swimnews*, Apr/May 2005

Colwin, C. To kick or not to kick - That was the question. *Swimnews*, Jun/Jul 2005

Colwin, C. Whatever happened to the freestyle 'catch'? *Swimnews*, Feb/Mar 2005


Osmond, G. Swimming: how Australian exactly is the crawl?. *Sport Health* 23(2):9-10, Winter 2005.


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