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CATALOG ON REQUEST
Editor's Preview

Every swimming practice begins with a warm up and ends with a warm down. It is appropriate that the studies included in this issue begin with a comparison of warm up methods and ends with a comparison of warm down methods. Sandwiched between the warm up and warm down are studies on competitive anxiety, lactate profiles, and the importance of muscle power. In addition, there is a paper describing a possible method of prescribing and evaluating interval training sets.

The first paper (Romney) details a very practical study to compare the effectiveness of dry land and in-water warm ups. There is little chance that dry land warm ups would be preferred over in-water warm ups. However, there are instances when swimmers may not have access to a warm up pool immediately before their swimming event. This study provides evidence that a dry land warmup can be of benefit even if it is not as effective as an in-water warm up in improving a 100 yard freestyle performance. Perhaps later studies will examine whether dry land warm up influences performance in longer races such as 400 I.M., 400 m freestyle, and 1500 m freestyle.

The next two papers (Johnson and Bradshaw) describe studies relating to the importance of strength or power to sprint performance. The Bradshaw paper concerns the role of dry land power and shows that within a homogeneous group of swimmers, dry land power does not correlate significantly with sprint performance. One of the unique findings in this study, however, was that although there was no correlation between power and performance of the whole stroke, there was a significant correlation between power and arms-only performance. This implies that even in a homogeneous group, dry land upper body power has some role in determining performance. The Johnson paper explores the issue of strength and power further by adopting the premise that bench press, dry land power, and in-water power are measures of different strength/power components, all of which may contribute to performance in sprinting. This hypothesis was tested using multiple regression, a statistical method that evaluates the relative contributions of several variables make in determining performance.

The paper by Nordell examines various measures of anxiety in swimmers at practice sessions and at competition. It seems, from the results in this study, that how swimmers perceived their anxiety (whether positive or negative) may be more important than whether or not the anxiety is present in a swimmer preparing to compete. Furthermore, swimmers’ perception of anxiety seems based on past successes, failures, and external appraisals of past performances. This implies that swimmers may learn to perceive anxiety as positive or negative. This, in turn, has important implications for how coaches structure experiences early in the swimmer’s career.

The paper by Holroyd describes a mathematical model for analyzing results from lactate profiles. Specifically, methods are presented that are purported to describe a swimmer’s relative aerobic and anaerobic capabilities. The advantage of such an approach is that, within limits, a swimmer’s relative weakness and strength in energy metabolism can be described. With additional research this could lead to specific training prescriptions to focus more on improving anaerobic power in some swimmers while concentrating more on improving aerobic power in other swimmers.

The warm down paper by Beckett describes a simple study comparing an active (1000 yard) warm down swim with a passive 30 min recovery period. Results were evaluated based on whether blood lactate concentrations recovered faster with the active warm down. The results suggest that after swimming 500 yards in the active warm down, lactate concentrations had returned to a level as low as that achieved in 30 min of passive recovery. It remains to be shown, however, how much effect this accelerated recovery has on subsequent performance. Hopefully, additional research will now address the effects of warm downs on later performance.

The final paper included in this issue (Sharp) does not describe a specific study, but proposes a method to prescribe and evaluate interval training for swimmers. This method is not intended to be the final answer in interval training, but is meant as a catalyst to stimulate coaches to evolve their approach to dosing swimmers with interval training. The evaluation of interval training based on the relative amount of physiological stress promises to help coaches quantify the training loads in a specific manner so that objective evaluation of past seasons can be made. Such an approach also offers obvious advantages in planning for future training.

An aspect of this issue that is noteworthy is that four of the seven papers contained in this issue were either authored or co-authored by an active coach. The contributions made by coaches to the advancement of the science of swimming should not be underestimated and the presence of so many coaches in these papers is testimony that coaches’ contributions go beyond the pool deck and into the laboratory. The systematic development, evaluation, and subsequent dissemination of knowledge in a peer-reviewed journal is a demonstration of leadership and professionalism. To see coaches so closely involved in this process is both heartening and commendable.

Rick Sharp

Vol. 9 4 Fall 1993
The Effects of Swimming and Dryland Warm-Ups on 100-Yard Freestyle Performance in Collegiate Swimmers

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Abstract
To determine the relative effectiveness of swimming warm-up (SWU), dryland warm-up (DWU), and no warm-up (NWU) on 100-yard (100y) freestyle performance, 8 female and 4 male collegiate swimmers performed 2 trial swims on separate days following each of the 3 different warm-up (WU) modes. Each WU mode lasted 15 minutes. SWU required a 5-minute continuous freestyle swim at an intensity corresponding to a rating of perceived exertion (RPE) of 12 on Borg’s 15-point scale; 10 x 25y freestyle swims leaving every 30 seconds (30s) and building to 100y race pace within each repeat; and a second 5-minute continuous swim, this time at an RPE of 14. DWU required a 5-minute period of continuous rope-jumping at an RPE of 12; 10 x 15s of calisthenics with a 15s rest following each exercise; and another 5-minute rope jump, this time at an RPE of 14. NWU required subjects to sit or lie still for 15 minutes. The criterion task was begun 3 minutes after completion of the WU. Performance times following SWU were the fastest (60.21s), while times following DWU (60.31s) were faster than those following NWU (60.96s). Although the performance-time differential (−0.75s) between swims following SWU and NWU was the only comparison that reached significance (p < 0.05), the −0.65s differential (p = 0.054) between swims following DWU and NWU was large enough to suggest that at meets where a warm-up pool is unavailable, swimmers can optimize their physiological preparation through the use of a dryland warm-up. Index Terms: warm-up, ergogenic aids, swimming

Introduction
Physical warm-up (WU) has long been used in competitive sports to improve performance (8,11,23). While experimental evidence on WU’s effects is still somewhat inconclusive, abundant theoretical evidence supports the use of WU as an ergogenic aid (5,6,9).

Elevated temperatures induced by WU prepare the body for the rigors of competition by causing the following physiological alterations: 1) increased dissociation of oxygen from hemoglobin and myoglobin (1,8,11,23,25); 2) increased energy production through accelerated enzyme kinetics and substrate utilization (2,8,23,25); 3) decreased viscosity of the working muscle (8,11,23,25); 4) increased nerve impulse speed and nerve receptor sensitivity (11,23,25); 5) increased cardiorespiratory blood flow (5,8,16,23,25); 6) increased active skeletal muscle blood flow (8,11,20,23,25); and 7) increased lipid metabolism (2,15).

These thermal effects of WU increase the muscle's maximum contractile force (3), decrease the energy cost required to complete a given task (23), and increase reliance on aerobic energy production (20) and lipid metabolism (15). The improvement in maximum contractile force occurs as a result of reduced muscle viscosity, faster nerve conduction speed, and accelerated energy production (25). Lower energy cost is made possible by diminished muscle viscosity and heightened nerve receptor sensitivity (23). Greater reliance on aerobic metabolism stems from increased blood flow to the working muscle and the release of a greater percentage of the oxygen carried by that blood (8,20,23,25). This is an especially important effect in events requiring a significant energy contribution from anaerobic metabolism (13). For example, a WU preceding a 200y freestyle stabilized pH, decreased carbon dioxide concentration in the blood, increased activity of the bicarbonate buffer system, and decreased lactate and hydrogen ion concentrations in the working muscle (22). Increased reliance on lipid metabolism conserves glycogen in prolonged endurance events (20).
Because peak athletic performance requires that muscle and core temperatures be elevated at the outset of competition (1), swimmers might improve their performance by warming up immediately prior to their event. Because it allows for the practice effect and provides a more effective warming of event-specific motor units, a swimming WU (SWU) will probably be the most effective WU mode for a swimming event. However, when a WU pool is unavailable, a dryland WU (DWU) that elevates body temperature may allow swimmers to perform better than they would with no WU (NWU). This study, then, was designed to assess the effectiveness of 3 common WU modes—SWU, DWU, and NWU—on 100y (91.44m) freestyle performance in collegiate swimmers.

Methods

Subjects: Four male and eight female NAIA Division 1 swimmers volunteered for this study after being informed of its risks, benefits, and procedures. They had all passed a physical examination and been cleared for athletic participation. Subjects had been in pre-season training for at least 7 weeks. In addition to swimming, some also lifted weights and/or participated in aerobics classes.

Experimental Procedure: All testing was done at 8 a.m. during the eighth and ninth weeks of the fall training season. At least two days’ rest separated each trial.

In order to ensure consistent conditions among trials, subjects were asked to 1) avoid physical activity on the morning of each test; 2) drive to the pool rather than bike or walk (for those living off campus); 3) maintain a consistent diet, sleep schedule, and pre-test morning routine throughout the study; and 4) give their best effort for each trial swim. Consistency in subject preparedness among trials was further enhanced because one of the researchers (N.R.) also served as an assistant swim coach and thus held training volume and intensity relatively constant during the two weeks of the study.

WU intensity was prescribed and monitored by ratings of perceived exertion (RPE’s) rather than heart rate for two reasons: 1) The high conductivity of water caused signals from nearby heart rate monitors to interfere with one another. 2) Maximum heart rates frequently vary by as much as 20 beats per minute among individuals of the same age; maximum heart rates also differ with activity, being 10-13 beats per minute lower in swimming than in weight-bearing exercises such as jumping rope (19). Thus, RPE was the best prescriptive tool for maintaining a consistent effort level within and between WU modes.

Mechanical and bioenergetic improvements such as these peak when muscle temperatures are elevated 2-3 degrees Celsius and rectal temperatures, 1-1.5 degrees (1). Temperature elevations of this magnitude require a minimum of 10-15 minutes of exercise at 65-70% of maximum heart rate (8), with highly trained athletes sometimes requiring WU’s as long as 30 minutes (1). Although fine-tuned athletes can benefit from longer and more rigorous WU routines, sustained WU intensities above the individual’s anaerobic threshold will impair performance by depleting phosphagen and glycogen stores and raising metabolite concentrations (6,12,14).

While many different activities, passive and active, can be used to elevate body temperature and thus provide the “warming” component of a WU, formal WU’s (use of the same activity as the criterion task) are considered superior to informal WU’s (use of some unrelated activity) because they more effectively warm event-specific muscle fibers and connective tissues as well as provide for the practice effect (23). The practice effect allows athletes to become familiar with their surroundings and prepare appropriate neuromuscular pathways through rehearsal of the event’s movements (8,11,23). The duration of a formal WU’s practice effect is still unclear, but muscle and core temperature begin to drop soon after the WU’s completion, with muscle temperature returning to normal within 45-80 minutes (21).

Despite widespread theoretical support for WU’s ergogenic value, experimental evidence remains ambiguous (5,6,9), both in WU studies generally and in those using swimming as the criterion task (11). Improved swimming performances have been elicited by various means of pre-event temperature elevation: hot showers (4), hot baths, jogging, bicycling, and electromagnetic wave stimulation (21). In contrast, Thompson (11) was unable to improve swimming performance using informal WU methods; only a formal swimming WU produced faster times. Interestingly, deVries (7) reported that while a swimming WU improved freestyle and backstroke performance, it did not benefit breaststroke and butterfly efforts. However, the latter two strokes did respond favorably when preceded by a calisthenic WU.

This paper’s authors have observed that while competitive swimmers almost always warm up before a meet, they are much less likely to do so in the minutes immediately preceding their event, even when an hour or more separates the pre-meet WU period and their competition time. When the natatorium has only one pool, still fewer swimmers will perform a pre-event WU. When no WU pool is available, swimmers who want to actively warm-up before their events must use exercises that can be performed on or near the pool deck. Faced with this situation, most competitors will do nothing more strenuous than a few arm circles, shoulder stretches, or hops behind the block.

Subjects were given a detailed explanation of the concepts underlying Borg’s 15-point RPE scale and its application to monitoring intensity. They were also taken through SWU and DWU protocols twice each prior to the testing period in order to further acquaint them with
the RPE chart and the WU protocols. Prior to the beginning of WU on each test day, an RPE chart was displayed and subjects were verbally and visually reminded of the prescribed RPE numbers and corresponding descriptors for the first and last five-minute segments of each active WU.

Each subject performed a total of 6 maximum-effort, 100y freestyle trials, 2 following each of the 3 WU protocols. A counterbalance design assigned WU mode on a rotating schedule to avoid effects attributable to practice or altered fitness levels. The three 15-minute WU protocols proceeded as follows: 1) NWU required subjects to sit or lie on an exercise mat. 2) DWU consisted of a) 5min continuous rope jumping at RPE = 12 (''fairly light'' - '‘somewhat hard’’); b) a 5-minute period of the following exercises: pushups, situps, lunge jumps, back hyperextensions, surgical tubing butterfly pulls, performed for 2 cycles of the 5-exercise sequence with 15s on each exercise, followed by 15s rest; and c) another 5min continuous rope jumping, this time at RPE = 14 ('‘somewhat hard’’ - ‘‘hard’’). 3) SWU consisted of a) 5min continuous freestyle swimming at RPE = 12; b) a 5-minute period of freestyle sprinting (10 x 25y leaving every 30s and building to 100y race pace within each repeat; and c) another 5min continuous freestyle swimming, this time at RPE = 14.

The total swim began 3 minutes after completion of the WU. In the interim, subjects were allowed to don cap and goggles, and to sit, stand, walk, or talk as might be done preceding a competitive event. They were not allowed to continue warming up or to leave the area behind the blocks. Each subject was assigned the same lane for each of the 6 trials, and no lane lines were used.

A standard starting procedure was followed with the researcher's voice command substituting for a gunshot or electronic beep. The primary timing device was Colorado Timing's electronic touchpad system, and the back-up was a Selko 800 stopwatch with memory. Both timing systems were hand activated, and all times were recorded to the nearest hundredth of a second.

Statistical Analysis: A one-way analysis of variance with repeated measures was used to analyze 100y swim times across WU sets. When a significant F ratio was obtained (p < 0.05), a Scheffe' post hoc test was used to determine the location of the significant differences. All data are reported as the mean ± or - the standard error.

Results

Subject characteristics are presented in Table 1.

100y Freestyle Performance Time: The influence of the 3 WU procedures on subsequent 100y freestyle time is illustrated in Figure 1. Data analyses indicated a significantly faster swim time (60.21s) following SWU than following NWU (60.96s). Although a difference of 0.65s was observed between DWU (60.31s) and NWU,

<table>
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<th>Table 1 Subject Characteristics, Mean (±SE)</th>
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<td>Weight (kg)</td>
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Figure 1. Mean (±SE) performance times for 100-yard freestyle following no warm-up, dryland warm-up, swimming warm-up.

it was not significant (P = 0.054). A much smaller difference (0.10s) separated SWU and DWU. On a relative scale (using SWU as the baseline value), swim times following DWU and NWU were slower by 0.17% and 1.24%, respectively.

Discussion

The results of this study demonstrated a hierarchy of WU effectiveness that was not unexpected given the established theoretical and emerging practical evidence of WU's ergogenic value. SWU was more effective than NWU for several likely reasons. First, SWU was designed to elevate body temperature, and although temperature was not directly monitored, WU intensity and duration were considered sufficient to induce muscle and core temperature increases (8,11,23). Associated with these systemic and tissue temperature increases are well-recognized physiological changes that reduce tissue resistance, facilitate oxygen transport and delivery, enhance substrate availability and energy production, and prime the organs and associated structures of the cardio-respiratory system (8,11,23,25).

In addition, a direct practice effect was provided by SWU's formal, motor-specific protocol. Environmental familiarization and neuromuscular facilitation are both positively influenced by skill-specific practice with the latter being more relevant to the results of this study. Because subjects trained regularly in the testing facility, they were already familiar with the pool and its surround-
ings. More likely beneficial was the opportunity to practice and refine proprioceptive and kinesthetic senses through rehearsal of the event's movements.

Additionally, it is possible that subjects swam faster with SMU simply because they believed they would. While there is no way to disprove a "placebo" influence in studies such as this, several precautions were taken to minimize such an effect. First, all potential candidates were interviewed to ensure that they had no bias against swimming a 100y race without a WU. Only those who avowed no fear of injury and no preconceived notions regarding their ability to perform at maximum effort without WU were selected. Second, subjects were told that the study's purpose was to assess the effectiveness of different WU modes, but they were never informed of the experimental hypothesis. Third, the researchers withheld swim times and any comments on trial performances until after completion of the study.

SWU was slightly more effective than DWU for 3 reasons. First, while DWU was SWU's equal in elevating overall body temperature, it was not able to prepare event-specific muscles in the same precise manner as did SWU. The closest dryland approximation of the freestyle stroke, the surgical tubing butterfly pulls, only crudely mimicked swimming's actual movements and resistances. Not only was SWU probably more effective in preparing event-specific muscles, but it may also have been less fatiguing. Because subjects were highly adapted to the demands of swimming, they probably carried less residual fatigue into the trial swims following SWU than into trial swims following DWU, to which they were not adapted. Furthermore, SWU allowed neuromuscular rehearsal of the event's movements, and although the significance of this practice effect is unquantifiable, no DWU can possibly reproduce the motions of swimming and the properties of its fluid medium.

Consideration of the time differentials for swims following each of the three WU modes indicates that the general thermal effects of WU may be the most significant contributor to improved performance. Despite minimizing residual fatigue and providing for the practice effect and more precise activation of event-specific muscles, SWU times were only 0.17% faster than DWU times, which were 1.06% faster than NWU times. Thus, if the total available WU effect is represented by the difference between SWU and NWU (1.23%), DWU was 86% effective.

**Applications**

This study attempted to compare the effectiveness of three common WU modes—SWU, DWU, and NWU—in order to assess DWU's value as a substitute for SWU in cases where a WU pool is not available during competition.

While the only intra-mode comparison to demonstrate statistical significance was that of SWU vs. NWU, the 0.65 second average time reduction offered by DWU over NWU was large enough to establish significance at the 94.6% confidence level using the stringent Scheffe's post hoc test. While falling just short of achieving significance at P < 0.05, the swim time difference between this study's DWU and NWU could and often does determine the top several places in championship races. For example, only 0.11 seconds separated women's places 1-5 in the 100y freestyle at the 1990 NAIA Nationals; only 0.13 seconds separated mens' places 1-3 (10).

Because similarly brief margins of victory can be found in all strokes and distances at all levels of swimming, the potential performance gain from performing a pre-event WU, even if it must be a DWU, is considerable.

It seems possible that with tailoring to the individual athlete, DWU could be designed to even more closely approximate SWU in its ergogenic potential. As mentioned above, this study's subjects were not trained in the dryland exercises. Evidence suggests that subjects unaccustomed to a particular physiological stimulus lack the cellular and enzymatic adaptations to fully benefit from WU with that stimulus and that even relatively brief and gentle WU's can fatigue them (17). While the swimmers in this study were not untrained, they were also not adapted to the rigorous of the dryland exercises. Perhaps if competitors performed a dryland routine prior to their regular swimming practice on 2 or 3 days each week they could more fully reap the benefits of a DWU.

While WU routines will vary with the athlete, event, and available facilities, some general WU guidelines can be suggested. Ten to fifteen minutes of activity at 65-70% of maximum heart rate will elevate body temperature to the desired level as indicated by the onset of sweating at room temperature (8). WU intensities above the anaerobic threshold should be avoided as they may impair performance (6,12,14). While some highly conditioned athletes may need as long as 30 minutes of WU activity to achieve optimal temperature elevation (1,8), the initial 5 minutes of WU produce most of the performance benefits available in a longer routine (1).

Because of the unpredictability of swim meet schedules, it would seem prudent for swimmers to begin warming up 20-30 minutes prior to their event. Such a practice could accommodate last-minute alterations in meet schedule and still preserve the thermal effects of WU, which last up to 40 minutes (21). While any activity that demands use of the major muscle groups will elevate body temperature and thus provide a WU effect (23), the ergogenic benefits of WU will be much more dramatic in athletes adapted to the WU exercises (17). For its WU, this study chose rope-jumping and simple calisthenic exercises because such a routine required minimal equipment and could be performed at deckside.

Regardless of the activities used, however, pre-event
WU has the potential to improve swimming performance. Most swimming races are 100's and 200's, events that place considerable demands on anaerobic energy pathways. Because such events are too brief to provide an intrinsic WU effect, performance in them is most amenable to the benefits of pre-event WU (11). In the 100-yard freestyle, for example, the body derives approximately 65% of its total energy from glycolysis and 25% from the ATP-CP pathway (18). Thus it would seem advisable for swimmers to use a pre-event WU and for coaches to continue to experiment with different WU modes and protocols. In recognition of a pre-event WU’s ergogenic potential, legendary Australian swim coach, Forbes Carlile (4), points out that “even a 1% difference is of considerable importance.”

References
Relationship of Swimming Power and Dryland Power to Sprint Freestyle Performance: A Multiple Regression Approach

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Abstract
Twenty-nine male subjects (20 collegiate swimmers and 9 high school swimmers) were tested in an effort to examine the intercorrelations among dryland power, swimming power, strength, and sprint freestyle performance. An additional purpose was to develop a prediction equation using a stepwise multiple regression analysis for the purpose of predicting sprint performance from a combination of the strength/power variables. Dryland power was measured on a Biokinetic Swim Bench while tests of swimming power were performed with a Power Rack modified to measure the time it takes to lift weights over a given distance in the rack. Strength was determined as 1 repetition maximum bench press on a Universal multi-station gym. The combination of peak power on Power Rack, power on Power Rack at a resistance of 1.5 kg, and power on Power Rack at a resistance of 7.8 kg predicted sprint velocity with greatest accuracy and resulted in a significant multiple correlation of $R = 0.91$. It is concluded that in the sample population used in this study, swimming power, but not dryland measures of strength or power, represents component(s) necessary for success in sprint freestyle swimming. Furthermore, it is concluded that this isotonic device (Power Rack) is a viable testing device that can be used throughout a season to assess swimmers' progress in developing swimming power and performance. Key words: Performance, power, strength, swimming

Introduction
While some investigators have reported high correlations between sprint performance and dryland power (4,7,8), others have attempted to correlate performance and power derived during actual swimming (1,2,5,9). Recently, a commercially available apparatus has been introduced in an attempt to increase swimmers' power in a highly specific manner. This apparatus (Power Rack, Total Performance, Inc., Mansfield, OH) allows a swimmer to swim tethered at the waist, while pulling weights through a pulley system. This system may have promise to easily assess and predict performance throughout the season.

The purpose of this study was to assess the power output of swimmers in the water with the use of a power rack, as well as on land, in order to examine possible intercorrelations with sprint performance. Furthermore, because of its use by many coaches, a one repetition maximum (1 RM) bench press was performed and examined for correlation with sprint performance. Competitive collegiate and high school aged male swimmers served as the subject population.

Methods
Twenty-nine male swimmers ranging in age from 14 to 22 yr volunteered for this study. Informed consent as outlined by the institutional human subjects in research committee was obtained prior to the study. Subject characteristics are shown in Table 1.

Table 1. Subject characteristics.

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<thead>
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<td>Weight (kg)</td>
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<td>9.3</td>
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<tr>
<td>Arm Length (cm)</td>
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</tr>
<tr>
<td>Body Surface Area (m²)</td>
<td>1.97</td>
<td>0.14</td>
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</tbody>
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Measurements
Swimming velocity, swimming power, biokinetic
power, and 1 RM bench press strength were determined for this investigation. Testing for all subjects occurred on two separate days. On the first day of testing, subjects were tested for sprint performance over 22.86 m (25 yd) and swimming power. On the second day of testing, subjects were tested for dryland power on a Biokinetic Swim Bench and for strength using 1 RM bench press. Anthropometric measurements of height (Ht), weight (Wt), body surface area (BSA) based on Ht and Wt (3), and arm length (ARM - distance between acromion process and most distal part of the hand) were also recorded and used in the analysis.

Swimming Velocity
Swimming velocity was determined using a timed 22.86 m sprint freestyle swim. Subjects were allowed 3 time trials with intertrial periods of at least 5 min. Timing began as the subject's feet left the wall on an underwater push-off and was stopped when the swimmer's fingers touched the opposite wall of the 22.86 m pool. Each subject's fastest mean velocity was used for the data analysis.

Swimming Power
Swimming power was assessed using a Power Rack (PR) modified with an electronic timing system. Two unimax microswitches (G.C. Electronics, Rockford, IL) were placed on the PR and were used for starting and stopping the timer. These microswitches were connected to a digital millisecond timer (Marietta Apparatus Co., Marietta, OH). The PR allows a swimmer to swim resisted by weights with a measured cable attached to their waist. The subjects swam one time at each resistance of 0.5, 1.5, 3.1, 4.7, 6.2, 7.8, and 9.3 kg. These weights were determined by balancing water with the weight plates and outgoing cable on the PR. Power values were calculated from the tethered swimming using the formula: \((\text{force} \times \text{distance}) / \text{time}\), where force was the weight pulled by the swimmer, distance was the length swum while being timed, and time was the amount of time necessary to perform the work. The power values were expressed in watts. Additional power expressions included peak power (highest power observed for the subject irrespective of resistance), power at 1.5 kg (power generated when pulling against the 1.5 kg resistance), power at 7.8 kg (power generated when pulling against the 7.8 kg resistance), power/stroke at each resistance, and power/kg body wt at each resistance.

Dry Land Power
Maximal dryland arm power was determined on a Biokinetic Swim Bench (Biokinetics, Inc., Albany, CA) as described earlier (8). The hands of the subjects were placed on the paddles with the arms extended. Each swimmer was allowed three practice pulls in order to become familiar with the equipment. Work was measured with the digital work integrator supplied on the bench. Power was calculated by dividing work by the time of the pull, which was measured by determining the length of a force curve produced by a chart recorder and making the calculation based on calibrated paper speed. Measurements were made on the best of three trials at speed settings of 0 (1.60 m/sec), 3 (2.05 m/sec), 6 (2.66 m/sec), and 9 (3.28 m/sec). Measurements (absolute and expressed relative to body wt) recorded for each subject included peak power irrespective of speed setting and highest power for each of the 4 speed settings.

Bench Press
Using the methods of Jackson, et al. (6), a 1 RM bench press was determined on a Universal multi-station weight machine in order to assess upper body strength. The load the subject could lift, the 1 RM, was determined by increasing the load by 10 lb after each successful lift until the load became difficult to raise. The load was then increased by five pounds until a failing attempt was observed. Minimum intertrial rest was two minutes.

Data Analysis
Performance scores obtained from each testing device were correlated with the maximum mean velocity of the 22.86 m swim using a multiple linear regression with a stepwise regression technique. Briefly, this method seeks the best possible prediction of the dependent variable (sprint velocity) using the measured variables as predictors. Significant independent variables were added to the model when a variable added predictability to the regression equation at \(p < 0.05\).

Results
The average 22.86 m sprint velocity was \(2.04 \pm 0.11\) m/sec with a range between 1.72 and 2.31 m/sec. Mean values for other measured parameters are shown in Table 2. The correlation matrix for all variables initially included in the regression model is shown in Table 3. As shown in Table 3 the independent variables with the highest simple correlations with sprint velocity were peak power on PR (\(r = 0.87\)), power obtained on PR with a resistance of 1.5 kg (\(r = 0.88\)), power on PR with a resistance of 7.8 kg (\(r = 0.84\)), and power measured on the swim bench at speed setting 3 (\(r = 0.74\)). Significant independent variables were added to the model when a variable added predictability to the regression equation at \(p < 0.05\).

Results
The average 22.85 m sprint velocity was \(2.04 \pm 0.11\) m/sec with a range between 1.72 and 2.31 m/sec. Mean values for other measured parameters are shown in Table 2. The correlation matrix for all variables initially included in the regression model is shown in Table 3.
As shown in Table 3 the independent variables with the highest simple correlations with sprint velocity were peak power on PR (r = 0.87), power obtained on PR with a resistance of 1.5 kg (r = 0.88), power on PR with a resistance of 7.8 (r = 0.84), and power measured on the swim bench at speed setting 3 (r = 0.74).

Table 2. Means and SD for significant variables in multiple regression equation.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (m/sec)</td>
<td>2.04</td>
<td>0.11</td>
</tr>
<tr>
<td>Peak Power (watts)</td>
<td>85</td>
<td>23</td>
</tr>
<tr>
<td>LOW (watts)*</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>HIGH (watts)**</td>
<td>80</td>
<td>21</td>
</tr>
</tbody>
</table>

* Power developed on Power Rack when pulling against 1.5 kg resistance.
** Power developed on Power Rack when pulling against 7.8 kg resistance.

Table 3. Matrix of simple correlations.

<table>
<thead>
<tr>
<th></th>
<th>Velocity</th>
<th>PEAK</th>
<th>HIGH</th>
<th>LOW Biokinetic PRESS HT WT ARM BSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>0.67</td>
<td>0.70</td>
<td>0.85</td>
<td>0.74</td>
</tr>
<tr>
<td>PEAK</td>
<td>0.70</td>
<td>0.68</td>
<td>0.68</td>
<td>0.55</td>
</tr>
<tr>
<td>HIGH</td>
<td>0.85</td>
<td>0.70</td>
<td>0.52</td>
<td>0.74</td>
</tr>
<tr>
<td>LOW</td>
<td>0.74</td>
<td>0.68</td>
<td>0.52</td>
<td>0.55</td>
</tr>
<tr>
<td>Biokinetic</td>
<td>0.55</td>
<td>0.68</td>
<td>0.68</td>
<td>0.55</td>
</tr>
<tr>
<td>PRESS</td>
<td>0.55</td>
<td>0.68</td>
<td>0.68</td>
<td>0.55</td>
</tr>
<tr>
<td>HT</td>
<td>0.46</td>
<td>0.44</td>
<td>0.40</td>
<td>0.41</td>
</tr>
<tr>
<td>WT</td>
<td>0.57</td>
<td>0.55</td>
<td>0.50</td>
<td>0.55</td>
</tr>
<tr>
<td>ARM</td>
<td>0.30</td>
<td>0.44</td>
<td>0.43</td>
<td>0.29</td>
</tr>
<tr>
<td>BSA</td>
<td>0.57</td>
<td>0.68</td>
<td>0.65</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Velocity - m/sec in 22.86 m sprint; PEAK - peak power (watts) measured on Power Rack; HIGH - power (watts) measured on Power Rack at 7.8 kg resistance; LOW - power (watts) measured on Power Rack at 1.5 kg resistance; Biokinetic - peak power measured on Biokinetic Swim Bench; PRESS - 1 repetition maximum on bench press (kg); HT - height (cm); WT - body weight (kg); ARM - arm length (cm); BSA - body surface area (m²).

When all of the independent variables were analyzed through the stepwise multiple regression, the only variables which contributed significantly to the prediction of sprint velocity were power output at 1.5 kg resistance on PR, power output at 7.8 on PR, and peak power on PR. The equation for describing this relationship was:

\[ \text{Velocity (m/sec)} = 1.1659 + 0.0333 \text{LOW} - 0.0049 \text{HIGH} + 0.0056 \text{PEAK} \]

where

- LOW is power (watts) at resistance of 1.5 kg on PR
- HIGH is power (watts) at resistance of 7.8 kg on PR
- PEAK is peak power (watts) obtained from all settings on PR

The multiple correlation for this relationship was \( R = 0.91 \) with a standard error of estimate at 0.05 m/sec which converts to approximately ± 0.28 sec error over 22.86 m for the swimmers in this study. To help visualize the validity of the prediction of the swimmers' sprint velocity, their measured velocities are plotted against velocities predicted from the regression equation (Fig. 1).

**Discussion**

No other studies have used a stepwise multiple regression approach to evaluate the relative importance of different measures of strength and power. Therefore, the unique finding in this study is that although swimming power as measured on PR is a significant component of sprint freestyle performance, neither of the measures of dryland strength/power (swim bench and bench press) was observed to contribute significantly to the prediction of sprint velocity in the multiple regression analysis.

![Figure 1. Scatterplot of predicted velocities vs. measured velocities of 22.86 m freestyle sprint using multiple regression equation.](image)

This finding implies that whatever contribution dryland strength/power makes to sprint performance in these swimmers, it is reflected in the results obtained during the tethered swimming test. Therefore, inclusion of dryland measures in the prediction equation would be redundant and, therefore, unnecessary for swimmers in this subject population.

The results of this study demonstrated a significant relationship between swimming power and sprint freestyle performance, confirming earlier studies (1,2,5). Costill et al. (1) reported a simple correlation of \( r = 0.82 \) be-
between swimming power and sprint velocity when testing competitive swimmers on a Biokinetic bench adapted for in-water testing. This correlation is very close to the simple correlation obtained in the present study between peak power on the PR and sprint velocity ($r = 0.87$). Hopper et al. (5) reported a correlation of $r = -0.80$ between 50 m sprint time and power/stroke during tethered swimming, which is also similar to the present findings.

The finding that dryland power as measured on the swim bench was not a significant independent variable in the stepwise regression is not surprising in light of other earlier studies. Although an early study (8) found a close relationship between power on the swim bench and sprint performance, the subject population in this early study exhibited a wide range of power (36-490 watts) and sprint performance. The subjects of the present study represented a more homogeneous sample as far as swim bench power is concerned (331-647 watts). In addition to the more homogeneous sample in the present study, the swim bench power output of all but one of the subjects was greater than 400 watts. An earlier study reported that, above a power output of about 500 watts, the relationship between dryland power and performance is not linear (7). These investigators concluded that above 500 watts, dryland power becomes less important than other factors including more efficient biomechanics of propulsion and reduction of body drag. These observations are consistent with the findings of the present investigation in that power produced when pulling high resistance on the PR likely reflects mostly the swimmers' propulsive power since the forward velocity is so slow that body drag is probably not a large factor in determining their power output. In addition, the power produced when pulling a low resistance on the PR likely reflects the combined contribution of propulsive power and minimized body drag since improvement of either of these components could result in improved power scores. That both of these measures of power on PR were found to be significant variables in the multiple regression implies that more effective propulsion mechanics and minimized body drag are indeed more predictive of sprint performance than is dryland power in swimmers at the ability level of those in this study.

**Practical Applications**

The finding of such a high relationship between power as measured on PR and sprint freestyle performance implies that testing and training on such a device is highly specific to swimming. Although partially tethered swimming had already been shown to be highly correlated to sprinting in collegiate swimmers, the present study shows that a similar result can be obtained with a isotonic device. In fact, it is likely that nearly any form of partially tethered swimming would yield similar results. Such devices may include surgical tubing or swimming tethered to buckets suspended over the pool deck with pulleys.

In light of the high relationship between power produced during partially tethered swimming and free swimming, it is reasonable to assume that this would be an effective form of strength/power training that offers a great deal of specificity. However, to confirm this assumption, future studies should be conducted to determine if improved tethered swimming power translates into measurable improvements in sprint performance. Furthermore, it would be interesting to determine if other commonly used forms of strength training produce gains in swimming power. It is apparent from the results of this study that bench press is not sufficiently specific for us to expect that improvements in bench press strength would result in improved swimming power or sprint performance. However, it must be acknowledged that this study merely identifies relationships among variables and a complete study of the role of bench press strength would require testing the effect of bench press strength training on sprint performance.

Specific recommendations for power training on partially tethered devices such as the Power Rack cannot be made from the results of the present study. However, in the course of testing, it was noted that when subjects were tested with the higher resistances on the PR, their stroke patterns appeared to be altered considerably. In general, the swimmers seemed to adopt a rather straight-back pull pattern. Whether daily training under this circumstance would affect mechanics used during free swimming is unknown at present, but coaches who use this form of training routinely should carefully monitor their swimmers' stroke mechanics upon switching back to free swimming.

The prediction equation generated by the multiple regression analysis is useful in assessing the relative contributions of the independent variables used in the analysis. However, coaches and/or researchers may be able to use this equation as a diagnostic tool. For example, consider the following two swimmers' test results:

<table>
<thead>
<tr>
<th></th>
<th>LOW</th>
<th>HIGH</th>
<th>PEAK</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>20</td>
<td>62</td>
<td>125</td>
<td>1.94 m/sec</td>
</tr>
<tr>
<td>MB</td>
<td>26</td>
<td>62</td>
<td>80</td>
<td>2.18 m/sec</td>
</tr>
</tbody>
</table>

Subject AT is obviously capable of generating a great deal of propulsive power as shown by the high scores for HIGH and PEAK. Both of these values reflect power produced when resistance is heavy and speed is consequently low. When tested at LOW, however, AT's power is relatively small implying that when swimming fast, AT either experiences a great deal of body drag which reduces his velocity and lowers his power output, or else he is unable to produce high forces in fast contractions. As a result, his predicted velocity is 1.94 m/sec or approx...
imately 11.8 sec for 25 yd. Subject MB, on the other hand, has a higher power at LOW even though his propulsive power when heavily resisted is quite low as compared with AT. Because the regression equation gives a greater weighting to the power score at LOW, MB's predicted velocity is 2.18 m/sec or 10.5 sec for 25 yd. To improve AT's sprint performance, the coach might recommend, based on these results, increased emphasis on reducing body drag and on maintaining propulsive efficiency when swimming at fast velocities in practice. Subject MB might also benefit from such an approach but could also likely benefit somewhat from increased emphasis on developing propulsive strength/power through heavy-load tethered swimming, or perhaps dryland training.

Whether this application of the present results would be effective will require further study, and coaches who wish to try such an approach should keep in mind the subject population upon which the multiple regression equation is based. It is possible if not likely, for example, that the regression equation for females would be significantly different from males and use of this equation for female swimmers would be inappropriate. Clearly such studies also need to be performed with swimmers from both genders, different stroke specialties, and different age groups before a complete analysis can be performed.

In summary this study has shown that power measured during a partially tethering device (Power Rack) bears a highly significant relationship with sprint freestyle performance. In addition, measures of dryland strength (bench press) and power (swim bench) were found not to contribute significantly to this relationship when using a multiple regression approach. Possible reasons for the lack of significant relationships between sprint performance and the dryland measures include lack of adequate specificity to the movement patterns used in swimming and the fact that the tested population used in swimming and the fact that the tested population was both quite skilled and possessed high levels of upper body strength and power.

References
Correlation Between Sprinting and Dry Land Power

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Jim Hoyle, M.A., M.Sc.

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Halifax, Nova Scotia,
Canada B3H 3J5

Abstract
This study examines the relationship between upper body power and freestyle sprinting speed, with an attempt to control the stroke cadence, and the relative contributions of the arms and the legs to the total speed of the swimmer. A significant correlation ($P < 0.05$) was found between biokinetic swim bench power and arms-only freestyle time over 25m. Full stroke swimming time did not correlate significantly ($P > 0.05$) with power. It was concluded that upper body power development and maintenance should be a regular part of the training program of all but the fastest swimmers. The subjects were seven, university age, proficient freestyle swimmers with at least three years competitive experience. The limitations inherent in attempting to simulate real swimming on the swim bench and the small number of subjects in the study are discussed. key words: upper body power, swimming speed, swimming cadence

Introduction
Some studies have found a strong relationship between freestyle sprint time and the capability of the performer to produce power with the upper body (1,2,4,8,12,17). Conversely, other workers have found no significant correlation, depending on the method of power measurement (2,5,15). Variation in other factors such as "propelling efficiency", that is, the ratio of "useful power to overcome drag" to the total power generated by the swimmer (15) were held to account for differences between swimmers' performances (17). This seems to be especially true for nationally ranked athletes.

Nevertheless, the validity of the relationship seems to be obscured in some studies through the use of groups heterogenous in age (4,9), gender (2,12) and possibly development (5,9,12). Problems associated with heterogeneous grouping of swimmers have long been recognized (1,11).

Although a number of problems associated with the direct measurement of power in a dryland situation have been obviated by the use of tethered (9) and partially tethered swimming (5), and an underwater fixed push-off point system (16), the biokinetic swim bench remains a convenient dry land testing and training instrument for clubs.

A limitation of the bench is that most swimmers, in order to produce as much power as possible, use a different pulling technique than is used in the water. The technique most often used for producing a maximum power measurement on the bench is likely to be less efficient in the water.

Another limitation is that swimmers use slightly different methods of propulsion in the water. Experts use whatever method they believe works best for their own strength level and body build. Some swimmers need to produce more power in order to go just as fast as someone who has less drag in the water (17).

The present study is different from those found in the literature in two ways. First, not only is sprint time taken, but also the legs-only sprint time and arms-only time are examined. Secondly, stroke rate is taken into account. The stroke rate has not normally been predetermined in power measurements on the swim bench, though it has been used in oxygen consumption determinations (13). The stroke rate for the water performance is used in this study to establish the pulling rhythm on the swim bench. It is hoped that this procedure will more effectively duplicate on the bench, the pull in the water, thereby more closely approximating the power produced during actual swimming. It is further expected that if an identical rate is used in dryland and pool situations, variation in stroke rate between subjects will have little effect on the analysis of the mean power generated by the swimmers.
This attempt to control the stroke rate may help to reduce the ambiguities in the literature and cast more light on the relative importance of power and technique. Consequently, the hypothesis of this study is that swimmers with faster sprint times, using an arms-only freestyle stroke, are capable of producing more power, as measured on a biokinetic swim bench and hence, a negative correlation will be found between those two variables.

Methods
The subjects were seven male university age, proficient free style swimmers with at least three years of competitive experience. Swim testing consisted of 9 x 25m sprints, each beginning in the water with a push off the wall. The sprints were separated by subject-controlled rest periods, putting the test well within their capabilities. The first 3 sprints were full stroke sprints, that is, the subjects used both arms and legs. The next 3 sprints were using legs-only, each subject using a flutterboard to help support the upper body. The last 3 sprints were arms only sprints. In this case, a pull-buoy was used to keep the legs stationary and also to keep them from sinking, thereby minimizing interference with the arm stroke. During the arm trials, the stroke rate was recorded by saying “stroke”! into a tape recorder every time the subject pulled with each arm. The average times for the 3 trials in each swimming mode were used as each subject’s sprint time. Timing was measured by stop watch.

The second part of testing involved the biokinetic swim bench. All subjects were thoroughly familiarized with the use of this equipment. The resistance setting of the ergometer corresponded to a speed of about 1.0 m/sec. This meant that if the swimmer attempted to swim at speeds equal to or greater than 1.0 m/sec, tension was developed along the pulling cable which would be registered as work output. This setting has been reported as optimum for most male high school and college swimmers (1). Subjects were instructed to attempt to duplicate their water performance in so far as pulling technique went, that is, to use alternate arms and, as far as was possible, to attempt an overhead recovery. A recorded tape of their pulling rate was played back to them and their individual rhythm established. They were not allowed to view the readout monitor, as this may have acted as an incentive to perform above their typical level.

The subjects were instructed to start their single trial when ready. Timing was started as the subject started the first pull. Timing was completed when the subject’s average time for the arms only sprint was reached. Thus, the arms-only sprint and the power bench trial comprised the same number of strokes as the well as the same time. The total work for the timed trial was recorded and converted to power output.

Correlations performed were Pearson Product Moment. Covariance of legs-only time with full sprint time was examined to attempt to eliminate the contribution of the legs from “whole” swimming, thus arriving at an independent calculation of arms-only time.

Results
The mean time for each sprint condition is shown in Table 1 for each subject. Correlations between each pair of sprint modes was .9 (P < .05) or higher in all cases. Work output for each subject is also shown. Table 2 gives the mean of the strokes each swimmer took in the full sprint mode and the power output determination. The mean power output for the bench-simulated 25m swim is also shown. Arm power correlated -.44 (P > .05) with the full sprint time and -.72 (P < .05) with the arms-only swim time.

Table 1. Performance times for each sprint mode

<table>
<thead>
<tr>
<th></th>
<th>Full sprint</th>
<th>Legs only</th>
<th>Arms only</th>
<th>Work (kpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(sec)</td>
<td>(sec)</td>
<td>(sec)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.0</td>
<td>21.9</td>
<td>16.6</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>14.9</td>
<td>20.9</td>
<td>15.7</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>13.7</td>
<td>19.2</td>
<td>13.6</td>
<td>179</td>
<td></td>
</tr>
<tr>
<td>13.6</td>
<td>21.0</td>
<td>15.3</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>13.1</td>
<td>18.9</td>
<td>14.9</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>12.7</td>
<td>17.0</td>
<td>14.0</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>15.5</td>
<td>23.4</td>
<td>18.2</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>14.07</td>
<td>20.34</td>
<td>15.47</td>
<td>144.4</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.98</td>
<td>2.01</td>
<td>1.45</td>
<td>29.8</td>
</tr>
</tbody>
</table>

Table 2. Stroke and power output of freestyle swimmers

<table>
<thead>
<tr>
<th>Number of strokes for 25m</th>
<th>Mean power for the simulated arms-only swim on the bench</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>64.4</td>
</tr>
<tr>
<td>20</td>
<td>105.5</td>
</tr>
<tr>
<td>19</td>
<td>129.0</td>
</tr>
<tr>
<td>19</td>
<td>86.5</td>
</tr>
<tr>
<td>21</td>
<td>67.8</td>
</tr>
<tr>
<td>20</td>
<td>126.1</td>
</tr>
<tr>
<td>23</td>
<td>73.3</td>
</tr>
<tr>
<td>Mean</td>
<td>93.23</td>
</tr>
<tr>
<td>S.D.</td>
<td>27.17</td>
</tr>
</tbody>
</table>

The scatter of power vs. performance is shown in Figure 1 for both arms-only and full sprint modes.
Analysis of covariance failed to yield an independent estimate of arms-only time.

Discussion
The expectation that the more powerful swimmers on the swim bench would also prove faster in the water using
arms only, has been realised in this group of athletes. The fact that the incorporation of leg action in the full sprint mode seems to interfere with this relationship does not invalidate the apparent need for substantial arm power in the faster swimmer.

![Graph](image)

**Figure 1. Scatter of biokinetic bench power and 25m swim time**

The times reported in the present study show the importance of the contribution of the arms. The relatively small difference between full sprint times and arms-only times argues for a minor propulsive contribution from the legs. This is also suggested by direct underwater observation of free-style technique, in which it is frequently seen that leg action is deemphasized. The arms-only technique obviously maximizes the effect of the legs if such a change in technique is common, it could also be responsible for the failure of the present study to estimate the contribution of the arms by eliminating the contribution of the legs using the arms-only times and analysis of covariance.

A source of error in this study is in the fact that the swim bench does not exactly duplicate swimming technique in the water. In the first place, the stroke mechanics are different, since the bench requires a lower level of arm recovery and also tends to minimize the S-shape of the conventional arm stroke. Secondly, there is no guarantee that the pulling techniques in the water and on the bench generate the same amount of power, so that the results of an investigation of power measured under one set of conditions but examined under another, could be spurious.

The small number of subjects (seven) is a limitation, even though a significant relationship was found. This deficiency reflects the difficulty of obtaining a relatively homogeneous group of subjects, from the point of view of both development and training experience. Small group studies have occasionally been shown to be useful in examining power and efficiency, with six male and four female subjects (14) and in looking at the effect of weight training on power and performance, with seven subjects (6).

A further source of error lies in the push-off start for the swim trials. This potentially confounding variable may, in a further study, yield to analysis of covariance.

The range of power generated by these subjects with alternate arm pulls (64-129w) is lower than some workers have found, which seems to depend on the method of determination. Values up to 490w have been reported (12) for double arm pulls on the biokinetics swim bench, while others have reported values only up to 185w (10), 220w (17) or 340w (7) under conditions similar to the present study. Partially tethered swimming has produced values in the same range as the present study (3), while an in-water fixed push-off point instrument has given measurements up to 172w for alternate arm action (16).

**Practical Applications**

It is important to establish whether there is a genuine relationship between arm power and sprinting speed within a group of swimmers at the same stages of development, since this would help to determine the direction of training emphasis. The observation that a power-speed relationship does not hold for very fast swimmers, those swimming faster than 2.1 m/sec (1), does not negate the advisability of developing and maintaining power for slower swimmers who are, after all, in the majority. This conclusion, that dry land power training should be part of a sprinter’s regular program, especially if pool time is limited, is also supported by other studies (17).

**References**


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Competitive Trait Anxiety, State Anxiety, And Perceptions of Anxiety: Interrelationships in Practice and in Competition

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University of Nebraska-Lincoln

Abstract

The purpose of this study was to determine the relationships between competitive trait anxiety, state anxiety, and perceptions of anxiety in a practice and a competitive sport situation. Twenty female collegiate swimmers from the University of Nebraska Swim Team volunteered for this study. Competitive trait anxiety was measured by the Sport Competition Anxiety Test (SCAT); state anxiety was assessed using the cognitive anxiety subscale of the Competitive State Anxiety Inventory-2 (CSAI-2); and perceptions of anxiety as either a positive or a negative influence on performance were measured by the Competition Anxiety Perceptions Scale (CAPS). The SCAT was administered 48 hours prior to the state measures. The CSAI-2 and the CAPS were administered in succession at the following times; one hour and 24 hours prior to a practice swim, and, one hour and 24 hours prior to a competitive swim. Performance in both practice and competition consisted of a 100 yard swim. Although no statistically significant relationships were found among competitive trait anxiety, state anxiety, and perceptions of anxiety, a significant relationship was found to exist between CAPS in practice and CAPS in competition. Similarly, results showed a significant relationship between CSAI-2 in practice and in competition. It is concluded that coaches can help athletes by exploring the positive affect of anxiety rather than the negative.

Introduction

Intense training and correct technique are obviously necessary in order to reach an advanced level in a given sport, such as swimming. However, in recent years several psychological factors have been recognized as influential, positively or negatively, in sports performance. Anxiety is one component that has received extensive study by researchers in the field of sport psychology (1,2,3,7,16,18).

Anxiety can be defined as an emotional reaction to a variety of stressful stimuli. Individuals may experience a high state of physiological arousal accompanied by feelings of discomfort and apprehension. In 1971, Spielberger differentiated between trait anxiety and state anxiety. Trait anxiety refers to relatively stable individual differences in anxiety proneness whereas state anxiety may be conceptualized as a transitory emotional state that varies in intensity and fluctuates over time. Trait anxiety (A-trait) is therefore a person’s overall level of anxiety and state anxiety (A-state) is a situational response.

In sports competition, anxiety is understandably widespread. Some athletes view the situational demands as a challenge and a source of excitement. Competition is perceived as motivating. In contrast, sports competition is perceived by other individuals as threatening, especially to one’s self-esteem, and thus these people may respond to a sports setting with an increased level of state anxiety. Martens (6) described these individual differences in the tendency to perceive competitive situations as threatening. He referred to it as competitive trait anxiety (CTA) and defined it as a stable factor of personality that interacts with situationally specific anxiety responses. Scanlan (13) reported that high A-trait individuals appraised competition as more threatening, as indicated by higher A-state scores, than low A-trait individuals.

Further research has shown that when anxiety is measured in competitive and noncompetitive situations, a difference exists (4,18). One factor that seems most important in determining level of competitive trait anxiety and state anxiety is whether the individual must perform in a noncompetitive, or practice condition, versus an actual competition. Simon and Martens (15) suggest that level of threat varies from noncompetitive to competitive situations, creating varied A-state reactions from individuals with differential levels of competitive A-trait.
Most of the existing research (11, 12, 18) focuses on the negative aspects of anxiety rather than its positive influences. It seems that some athletes may perceive the various levels of anxiety that they experience as negative and detrimental to performance. However, some athletes do find anxiety to have a positive influence on their performance. Experiencing high arousal states prior to athletic performance can produce feelings of extreme excitement and a readiness to compete rather than feelings of apprehension or worry. It appears that the athlete’s appraisal of the competitive situation as either threatening or invigorating plays a significant role in one’s view of anxiety as having either negative or positive affect. Very little research has been done on the positive perceptions of anxiety as they relate to enhancing performance. However, the paucity of information on the positive nature of anxiety does not detract from its importance as a viable concept.

Several researchers (5, 14) have investigated the positive influence that cognition and affect, specifically precompetitive anxiety, can have on athletic performance.Mahon andAvener (5) studied the affective patterns of elite male gymnasts (N = 12) at the United States Olympic Trials. Subjects completed a standardized psychological skills inventory 48 hours prior to the final qualifying meet. One factor which differentiated qualifiers (Olympic Team members) from nonqualifiers was their anxiety patterns prior to and during competition. Qualifiers tended to use their anxiety as a stimulant to better performance. The less successful gymnasts seemed to arouse themselves into near panic states. The researchers suggest that an athlete could be trained not to view anxiety as negative, but to focus and capitalize on its energizing properties in a manner conducive to enhanced performance.

In another study, Silva et al. (14) examined elite junior wrestlers in order to better understand positive psychological affect. The authors found the team qualifiers to be less depressed, angry, fatigued, and confused than nonqualifiers. Accordingly, qualifiers demonstrated more positive precompetitive affect than nonqualifiers. This study tends to support Morgan's (9) hypothesis that positive affect is related to better performance, and is especially prevalent in elite athletes.

Positive affect prior to competition may provide an athlete with a better foundation to deal with adversity or stress. A positive cognitive-affective mind set can lead to better performance. In contrast, a negative cognitive-affective mind set can only lead to more anxiety and doubt, and hinder performance. Therefore, based upon the ambiguity over positive and negative effects of anxiety, this study investigated the relationship between the different levels of anxiety and one’s perception of anxiety as being positive or negative in both a practice and competitive situation.

Methods

Subjects
Twenty female collegiate swimmers at the University of Nebraska-Lincoln volunteered for this study after being informed of purposes, risks, and possible benefits of the investigation. The subjects ranged in age from 18-22 years old. The mean age was 19.55 years.

Instrumentation

SCAT. The Sport Competition Anxiety Test for Adults (SCAT) is a situationally specific measure of competitive trait anxiety which measures an individual's tendency to perceive competitive situations as threatening. The SCAT is a self-report questionnaire consisting of 15 items which are answered according to a Likert-type scale (Hardly Ever, Sometimes, Often). Ten items are scored and five are fillers. Scores range from 10 (low competition anxiety) to 30 (high competition anxiety).

CSAI-2. The Competitive State Anxiety Inventory-2 (CSAI-2) is a sport specific and multidimensional anxiety measure which assesses state anxiety in the sports context. The CSAI-2 is a self-report questionnaire consisting of 27 items which are to be answered on a 4-point Likert scale (1 = Not At All; 4 = Very Much So). The 27 items are subdivided into three variables (cognitive anxiety, somatic anxiety, and self-confidence), with each factor having a minimum score of 0 (indicating a low level of the variable) and a maximum score of 36 (indicating a high level of the variable). This study specifically determined the CSAI-2 score using the cognitive anxiety factor.

CAPS. The Competition Anxiety Perception Scale (CAPS) is a 10-item self-report questionnaire designed to measure perception of anxiety in terms of it having a positive, neutral or negative influence on performance. Responses are based on a 7-point scale (-3 = Very Negative; 0 = Neutral; 3 = Very Positive). Scores range from 10 (very negative) to 70 (very positive). A score of 40 is considered to be neutral. The CAPS questionnaire is a relatively new instrument developed by Murray (10) who has used Cronbach’s Alpha to demonstrate internal consistency coefficients of .84, indicating a high degree of reliability.

Performance Measure. A stopwatch, significant to the one-hundredth of a second, was used to record the time required for each subject to swim 100 yards in a 25-yard pool.

Design of Study

This study utilized a cross-sectional design whereby data were collected while subjects were in actual training for their competitive season.

The data were collected after the female varsity swimmers had completed at least one-half of the competitive season. Data were collected once during practice and once during competition.
This study consisted of assessing each subject’s level of competitive trait anxiety and state anxiety, as well as each subject’s perception of anxiety as having a positive affect, neutral, or negative affect on performance.

Testing Procedures

The experiementer briefed all subjects at one time in the same location. Each subject provided informed consent in accordance with the procedures required by the Institutional Review Board at the University of Nebraska. The subjects completed the SCAT questionnaire and were then informed that they would swim 100 yards of their “best” stroke for time during a regular practice scheduled in three days.

Twenty-four hours prior to this practice condition the experimenter asked the subjects to complete the CSAI-2 and the CAPS in succession. The subjects were asked to complete this same procedure (respond to the CSAI-2 and the CAPS) one hour prior to the practice condition.

The following week, the subjects were again asked to complete the CSAI-2 and the CAPS which were administered twenty-four hours prior to and one hour prior to an actual competition in which the subject swam 100 yards of her “best” stroke.

The 100-yard swims during practice and competition were recorded by a manual timing system significant to the one-hundredth of a second.

Statistical Analysis

A 2 (Condition) x 2 (Time) ANOVA with repeated measures was utilized with both the CAPS questionnaire and the CSAI-2 questionnaire.

A multivariate correlational matrix was utilized to explore the relationship between SCAT, CSAI-2, and CAPS, which respectively measure competitive trait anxiety, state anxiety, and one’s perceptions of anxiety as having a positive or negative influence on performance. Outcome measures in both practice and competition conditions were included as variables in the matrix and a dependent t-test was used to compare mean performance time in practice and mean performance time in competition.

Results

Descriptive Data

Descriptive data for the SCAT, CAPS and CSAI-2 questionnaires as well as descriptive data for performance conditions are presented in Table 1. It is important to understand that 24P and 24C describe the administration of the questionnaire 24 hours prior to practice and 24 hours prior to competition. Similarly, 1P and 1C delineate questionnaires administered one hour prior to practice and one hour prior to competition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>X</th>
<th>± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCAT</td>
<td>23.85</td>
<td>± 3.10</td>
</tr>
<tr>
<td>CAPS 24P</td>
<td>39.10</td>
<td>± 9.48</td>
</tr>
<tr>
<td>CAPS 1P</td>
<td>40.85</td>
<td>± 8.70</td>
</tr>
<tr>
<td>CAPS 24C</td>
<td>40.35</td>
<td>± 9.25</td>
</tr>
<tr>
<td>CAPS 1C</td>
<td>40.30</td>
<td>± 8.99</td>
</tr>
<tr>
<td>CSAI-2 24P</td>
<td>14.75</td>
<td>± 3.64</td>
</tr>
<tr>
<td>CSAI-2 1P</td>
<td>16.10</td>
<td>± 3.88</td>
</tr>
<tr>
<td>CSAI-2 24C</td>
<td>17.75</td>
<td>± 4.52</td>
</tr>
<tr>
<td>CSAI-2 1C</td>
<td>19.05</td>
<td>± 4.56</td>
</tr>
<tr>
<td>Practice Swim</td>
<td>62.67</td>
<td>± 5.42</td>
</tr>
<tr>
<td>Competition Swim</td>
<td>61.99</td>
<td>± 5.36</td>
</tr>
</tbody>
</table>

Condition and Time Variables with the CAPS

Using a 2 (Condition) x 2 (Time) ANOVA with repeated measures, the interaction between condition of performance and time of anxiety assessment revealed a nonsignificant F ratio, F(1, 19) = 2.18, p > .05. However, the main effect for the condition factor and for time were found to be nonsignificant.

Condition and Time Variables with the CSAI-2

The main effect for condition was significant, F (1,19) = 11.90, p < .05. An analysis of time main effect also revealed significant results, F (1, 19) = 7.20, p < .05. In contrast, the 2 (Condition) x 2 (Time) ANOVA with repeated measures yielded a nonsignificant condition by time interaction.

Performance Times

To evaluate the difference in the 100 yard swim, a dependent t-test analyzed the performance times of each subject in practice and in competition. Results indicated a significant difference (p < .05) between mean performance times in practice (62.67 ± 5.42 sec.) and mean performance times in competition (61.99 ± 5.36 sec.).

Correlational Analysis

Pearson product-moment correlations were conducted to examine the relationships between the variables. An alpha level of p < .05 was used as criterion for statistically significant relationships.

All but two of the correlations between the variables were found to be nonsignificant. The relationship of CAPS in practice and in competition, and the relationship of CSAI-2 in practice and in competition both revealed significant correlations.

The correlations between the CAPS scores in practice and in competition are presented in Table 2. Highly significant correlations ranging from r = .80-.90 were found for all of the following contrasts:
a) CAPS 24P and CAPS 1P  
b) CAPS 24P and CAPS 24C  
c) CAPS 24P and CAPS 1C  
d) CAPS 24C and CAPS 1C  
e) CAPS 24C and CAPS 1P  
f) CAPS 1C and CAPS 1P  

The correlations between the CSAI-2 scores in practice and the CSAI-2 scores in competition are presented in Table 3. Significant correlations ranging from \( r = .49 \) to \( r = .89 \) were found for all of the following contrasts:

### Table 2 Correlations Between CAPS Practice and CAPS Competition Scores

<table>
<thead>
<tr>
<th></th>
<th>CAPS 24P</th>
<th>CAPS 1P</th>
<th>CAPS 24C</th>
<th>CAPS 1C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPS 24P</td>
<td>1.0</td>
<td>.8045*</td>
<td>.8983*</td>
<td>.8181*</td>
</tr>
<tr>
<td>CAPS 1P</td>
<td>1.0</td>
<td>.6504*</td>
<td>.8939*</td>
<td></td>
</tr>
<tr>
<td>CAPS 24C</td>
<td>1.0</td>
<td>.6916*</td>
<td>.4911*</td>
<td>.8822*</td>
</tr>
<tr>
<td>CAPS 1C</td>
<td>1.0</td>
<td>.5561*</td>
<td>.4968*</td>
<td>.8822*</td>
</tr>
</tbody>
</table>

*p < .05.

a) CSAI-2 24P and CSAI-2 1P  
b) CSAI-2 24P and CSAI-2 24C  
c) CSAI-2 24C and CSAI-2 1C  
d) CSAI-2 24C and CSAI-2 1P  
e) CSAI-2 1C and CSAI-2 1P

### Table 3 Correlations Between CSAI-2 Practice and CSAI-2 Competition Scores

<table>
<thead>
<tr>
<th></th>
<th>CSAI-2</th>
<th>CSAI-2</th>
<th>CSAI-2</th>
<th>CSAI-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSAI-2</td>
<td>1.0</td>
<td>.6916*</td>
<td>.5561*</td>
<td>.3845</td>
</tr>
<tr>
<td>24P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSAI-2</td>
<td>.6916*</td>
<td>1.0</td>
<td>.4911*</td>
<td>.4968*</td>
</tr>
<tr>
<td>1P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSAI-2</td>
<td>.5561*</td>
<td>.4911*</td>
<td>1.0</td>
<td>.8822*</td>
</tr>
<tr>
<td>24C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSAI-2</td>
<td>.3845</td>
<td>.4968*</td>
<td>.8822*</td>
<td>1.0</td>
</tr>
<tr>
<td>1C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05.

However, there was no significant correlation between CSAI-2 24P and CSAI-2 1C which were the two measures with the greatest time span difference.

### Discussion

The descriptive data in this investigation indicated that, as a group, the athletes tended to perceive competitive situations as threatening and that their state anxiety gradually increased as they approached competition. In addition, data from the CAPS questionnaire indicated that most of the subjects did not perceive feelings of anxiety as beneficial to performance. These perceptions did not significantly change across condition or time. Because this study was the first to use the CAPS across different conditions (practice versus competition) and different times (one hour versus 24 hours), these findings stand alone in the literature.

The present study also revealed that condition and time did not affect an athlete's perception of anxiety in regard to positive or negative influence on performance. However, results did provide evidence that an athlete’s state anxiety level differs between practice and competitive conditions. More specifically, when examining differences across condition and time with the CSAI-2 questionnaire, it is evident that state anxiety increases as competition nears.

Research by Murray (10) examined the CAPS questionnaire and the concept of positive anxiety, but did not correlate CAPS with sports performance. Therefore, the present study is unique as it is the first to examine this relationship. The results, although nonsignificant, suggest that the CAPS questionnaire may be measuring a stable characteristic (e.g., perception of anxiety) rather than a situational response. The questionnaire did not account for situational factors or intrapersonal factors which mediate the influence of one’s perception of anxiety on performance. Indeed, perceptions of anxiety (positive, neutral, or negative) appear to be based on previous cognitive appraisals of performance made over time. These past performances may include successes or failures and they become powerful influences on current performance appraisals.

This study is also the first to examine the interrelationships between CAPS and SCAT, and CAPS and CSAI-2. Analysis of these interrelationships indicated no significant correlation, but the findings could be attributed to a new questionnaire. Although there is a vast amount of literature which validates the use of the CSAI-2 as a state anxiety measure and the SCAT as a trait anxiety scale, the CAPS is a relatively new untested self-report questionnaire.

The findings of the present investigation indicate that future research should measure anxiety at different points in the season (e.g., preseason, midseason, and the end of the season) because of the fact that state anxiety tends to vary according to time and conditions. In addition, it would be of interest to explore differences in psychological characteristics between athletes who perceive anxiety as positive, and athletes who perceive anxiety as negative. Future research efforts should also be directed at identifying the causative factors of an athlete’s anxiety responses in competitive sports settings by utilizing multiple variables in the research design.

### Practical Applications

Some swimmers experience more anxiety than others, however as competition nears most athletes generally experience an increased level of anxiety. The anxiety arises out of the increasing amount of ruminations associated
with external situational cues including travel, seeing one's opponent, and putting on one's competitive bathing suit, as well as the self-generated expectations (internal and external) about performance. The athletes cognitively appraise the situation, that is to say they determine the importance of an event and their chances of success or failure. For example, how would an experienced swimmer appraise the United States Swimming Senior National Championships if he/she has been ill prior to the competition? Conversely, how would a healthy experienced swimmer appraise his/her chances of success knowing that his/her main competition was ill or injured? Such appraisals will then facilitate either high or low physiological activation and anxiety. If the situation is perceived as a threat, physiological activation may be appraised as negative. However, if the situation is perceived as a challenge the increased level of activation can function as a signal to the swimmer that he/she is ready to respond to situational demands.

Most coaches have witnessed competitive swimmers who focus on the negative effects of anxiety rather than the positive. As coaches we need to understand that we play a role in the athlete's perception of anxiety as positive or negative. It is possible to unintentionally communicate to the swimmer that nervousness or anxiety is "bad" by saying, "You swam poorly because you were nervous," or "You will swim slow if you are nervous and tense." Statements such as these, which suggest the negative effects of anxiety, may be inadvertently limiting the swimmer's performance emotion. Conversely, statements such as, "If you feel nervous, that could mean that you are really ready to go," may communicate the positive and energizing effects of anxiety.

As coaches, we can help shape swimmers' cognitive appraisals so that the results are beneficial. However, we must begin this process while the swimmers are young. It is imperative that coaches, especially age-group coaches, examine the positive side of anxiety and utilize their position of influence to communicate this to younger swimmers. Educating young age-group swimmers can be most effective as their perceptions and cognitive appraisals are still malleable and open to suggestion. For example, why not teach these young athletes that it is "good" to have "butterflies" prior to a race? Coaches should tell the swimmers that these feelings are "okay" and actually let the young athlete know that he/she is excited and ready to race.

Of course, some swimmers may become overly anxious and nervous. In this situation, perhaps coaches need to also teach young athletes ways to cope with feelings of anxiety. Practicing anxiety management skills will enhance the athlete's ability to control (increase or decrease) anxiety and perform at an optimal level.

Anxiety management techniques such as progressive relaxation, visuo-motor behavioral rehearsal (VMBR), biofeedback, hypnosis, and thought stopping are only some of the various techniques we can teach and implement. If we can assist swimmers to positively manage their anxiety they will have the potential for improving performance and consistency. Ultimately, learning such techniques to manage competitive anxiety can generalize or transfer to other common areas of concern for young athletes (e.g., test anxiety).

It is hoped that this study will contribute to a better understanding of positive anxiety and encourage coaches to teach their athletes about the performance enhancing effects of anxiety.

References


A Mathematical Model for Lactate Profiles and a Swimming Power Expenditure Formula for Use in Conjunction With It

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Abstract

Lactate profiles were obtained for 23 swimmers training with the City of Sheffield National Squad over a distance of 400 yards. The object was to find a mathematical formula which would describe the profile accurately. This would thus allow lactate values during competition to be estimated with some accuracy where competition times were available and would also allow the anaerobic threshold speed to be determined for each swimmer. A two part mathematical model consisting of a horizontal section followed by a rapidly rising exponential section as found to be a very good fit to the data and the above parameters were precisely calculated. A parameter characterising the slope of the rising section was also calculated for each swimmer. By using a swimming power expenditure formula in conjunction with the profile data it was also possible to calculate the proportions of aerobic and anaerobic power being expended at any swimming speed for each swimmer. Results are presented and discussed along with the possible applications of the method. Keywords: Lactates, Anaerobic Threshold, Regression Analysis, Swimming.

Introduction

Since their introduction by Mader (5), lactate profiles have been an accepted and commonly used measure of the state of the fitness of high level competition swimmers (6). However the use of lactate profiles is not without its difficulties. These include practical difficulties such as the number of finger or ear lobe pricks required and the time involved in swimming at several different levels of effort with a substantial recuperation period before each. In order to avoid these difficulties, coaches have evolved various test protocols with the use of fewer samples (3,8). However most test protocols make assumptions about the shape of the curve, an approximation which prevents careful individual curve fitting and thus loses information.

This paper describes a simple mathematical model which is shown to be a good fit to the data and which gives independent well defined values to both the lactate accumulation threshold speed and the slope of the profile at higher speeds. In addition a power formula is used, in conjunction with the profile data, to evaluate the relative proportions of anaerobic and aerobic power contributions in swimming performances. In particular they are evaluated for (a) competition swimming and (b) the speed which produces a blood lactate level of 3.5 mmol/litre.

Theory

Mathematical Modelling of the Lactate Profile.

A swimmers' lactate profile for any specified distance is a plot of blood lactate level immediately after completing a swim as ordinate against average swimming speed during the swim as abscissa for a series of swimming speeds ranging from \( V = 0 \) up to the maximum speed which the swimmer can sustain for the distance. It is important that each swim should be swum at as near constant speed as possible and that time for full recovery should be allowed between swims. A minimum recovery time of 10 minutes is essential.

The lactate profile obtained in this way is found to consist of two quite distinct parts (Fig. 1). These parts are: (a) a horizontally running section starting at \( V = 0 \) and ending at the lactate accumulation threshold speed \( V = V_a \), during which the blood lactate level changes little, if at all, remaining at the resting level \( L = L_o \) and (b) a rapidly rising section which begins at \( V = V_a \) and ends at the maximum speed that the swimmer is capable of over the distance.
Figure (1) A typical lactate profile for the swimmer ML plotted on linear axes with lactate level as ordinate and swimming speed as abscissa. Note that the rising part of the profile is both abrupt in onset and steep.

It is found in practice that the change from section (a) to section (b) is quite abrupt with a well defined threshold speed $V_T$ and that both $V_T$ and the slope of the rising part of the curve change with increasing or decreasing fitness.

It is also found empirically in our own data that the rising portion of the profile is a very good fit to an exponential function of the type:

$$L = \exp(\text{SV}) \text{ where } S \text{ is a constant} \quad \text{Eq 1}$$

A plot of this type is shown in Fig. 2 in which the alternative format $\ln L = \text{SV}$ is used by plotting the values $L$ on a logarithmic scale as ordinate with linear values of $V$ as abscissae.

Exponential equations of this kind are common in biology and usually arise as the solution of a simple differential equation, which itself is the mathematical statement of a straightforward biological effect. In this case the simplest form of such a differential equation is

$$\frac{dL}{dV} = S \times L \quad \text{Eq 2}$$

As a quantitative statement this equation describes a fact which is not self-evident, namely that at any given speed above $V_T$ the rate of rise of blood lactate level with increasing speed on successive swims is proportional to the lactate level at the present speed.

Solving equation 2 by separation of variables produces an equation which is slightly more complicated than equation 1

$$\ln \left(\frac{L}{L_0}\right) = S \left(V - V_T\right) \quad \text{Eq 3}$$

and states that the logarithm to base $e$ of the ratio of the observed lactate level to the resting level $L_0$ is a linear function of the increase in velocity above the threshold speed $V_T$.

Figure (2) An exponential plot of a lactate profile. The same data as in figure (1) is plotted on a log/linear paper. The rising part of the profile is now linear.

Below and at $V = V_T$

$$L = L_0 \quad \text{Eq 4}$$

Thus our mathematical model consists of two parts: equation 4 for the range $0 < V < V_T$ and equation 3 for the range $V > V_T$.

Figure 3 shows the same data as in Figure 2 plotted as $(L/L_0)$ on a logarithmic scale against $V$ in accordance with equation 3. By calculating $\ln (L/L_0)$ for each of the observed data points and using the corresponding values of $V$ we can fit a least means squares regression line to the data. Knowing $L_0$, $S$ and $V_T$ are easily found.

The speed $V_T$ found this way is the maximum speed at which the swimmer can swim the distance aerobically in the sense that there is no evidence of lactic acid accumulation and there is no evidence of an oxygen debt from the whole blood sample taken at the end of the swim. This does not rule out possible lactic acid production during the swim but it is has been metabolised by aerobic mechanisms at the time of taking the sample. The power expended while swimming at this speed is therefore the maximum aerobic power without lactate accumulation available to the swimmer when swimming this distance. As such this power expenditure may be
A Mathematical Model for Lactate Profiles and a Swimming Power Expenditure Formula for Use in Conjunction With It

Figure 3 An exponential plot of the same data as in figures (1) and (2) but this time with the ratio (L/Lo) as ordinate with swimming speed as abscissa in accordance with equation (3). The lactate accumulation threshold velocity is the speed above which (L/Lo) begins to exceed 1.

Resistance to motion of a body moving through a fluid when the flow around the body is turbulent is the case with swimmers. Textbooks of College Physics describe this situation using an equation:

\[ D = AV + BV^2 \]  
Eq 5

Where \( A \) and \( B \) are constants and \( V \) is speed as before (4). In practical situations \( A \) is found to very small and can be neglected so equation (5) becomes

\[ D = BV^2 \]  
Eq 5A

If we assume that equation 5A is directly applicable in the swimming situation then we can write down an expression for the power being expended by the swimmer:

\[ \text{Power} = \text{Force} \times \text{Velocity} \]

In the case of a swimmer, the force being exerted must be equal and opposite to the retarding force or drag so we can write

\[ P = D \times V \]  
Eq 6

Substituting D using 5A we get

\[ P = B \times V^3 \]  
Eq 6A

Unless we know \( B \) we cannot evaluate the power directly but we can use equation 6A to compare swimming power expenditure at two different speeds. As stated above the power output at the lactate accumulation threshold speed \( V_T \) is arguably the maximum purely aerobic power which the swimmer can sustain so substituting in 6A we get

\[ \text{Aerobic Base Power} \ P_T = B \times V_T^3 \]  
Eq 6B

Similarly we can argue that the power output during competition is the maximum power available including both aerobic base and total anaerobic contributions. Again substituting in 6A we get

\[ \text{Maximum Power} \ P_{\text{comp}} = B \times V_{\text{comp}}^3 \]  
Eq 6C

Dividing 6C by 6B we get

\[ P_{\text{comp}}/P_T = V_{\text{comp}}^3/V_T^3 \]  
Eq 7

Equation 7 allows us to evaluate the relative percentages of aerobic base and total anaerobic power contributions during competition swimming. By substituting another speed for \( V_{\text{comp}} \) in equation 7 we can evaluate the relative power contributions at any speed.

**Method**

It was decided to use the analysis described above to analyse lactate profile data from a number of swimmers training with the City of Sheffield National Squad in order to investigate the following:

1. The "goodness of fit" of the above mathematical formulation to the actual profiles obtained using
a Chi-squared index as described below.

2) To determine the lactate accumulation threshold velocity \( V_T \) for each swimmer.

3) To characterise the rising part of the profile by determining the increase in speed in m/sec between lactate values of 5mmol/litre and 10 mmol/litre. This value is denoted \( dV_{S/10} \) and is related to the slope parameter \( S \) (see equation 3) being equal to \( (\ln2)/S \) or 0.693/S. This relationship makes it easy to calculate and it can then be used to calculate other expressions of the slope parameter such as the time reduction in swimming a 400m swim obtained by doubling the final lactate level.

4) To determine the lactate level reached during competition for each swimmer given that 400m swimming times were available and that the swimmer’s degree of fitness was the same as during competition. It is assumed that the lactate level reached in competition would be very nearly the same as that reached in swimming a profile swim at the same speed.

5) To determine the relative aerobic and anaerobic power contributions at competition speed using equation 7 subject to the same provisos as in (4).

6) To determine the relative aerobic and anaerobic power contributions at the conventional VOBLA point (Velocity of Blood Lactate Accumulation) which is generally taken as being that speed which produces a blood lactate of 3.5 mmol/litre. This speed is denoted \( V_{3.5} \) in this paper. Twenty three swimmers in all took part in the study and a lactate profile was obtained for each one. The distance chosen for the swim was 400 yards as 12 lengths of a 33 1/3 yard pool. This was before the present facilities used by the squad became available. Each swimmer went through a standard warm-up procedure and was then rested for 10 minutes before taking an initial blood sample by thumb or finger prick to determine the resting lactate level. The swimmer was then asked to swim a 400 yard swim at constant speed, swimming for a time selected by the Chief Coach and based on the swimmer's known ability. The swims were carefully timed both overall and as 100 yard splits in order to monitor constancy of speed. At the end of each swim, the swimmer was asked to leave the water and sit in a canvas tubular frame chair, following which a thumb or finger prick blood sample was obtained. Sampling time was about 1.5 minutes after the completion of each swim. The swimmer was then rested for 10 minutes after which the procedure was repeated with a new and faster target time. In all each swimmer swam 4 times at steadily increasing levels of effort with speeds ranging from just above \( V_T \) to close to competition speed. The five whole blood samples obtained were later analysed for lactate concentration using a Clandon Model 23L blood lactate analyser. Samples were not lysed. Results were then inspected for constancy of speeds following which the data from the rising part of the profile was formulated as paired values of \( \ln (L/L_0) \) and \( V \). These data were then fitted to a linear regression line using a least mean squares fit in accordance with equation 3. The regression coefficients obtained enabled the parameters \( V_T \) and \( S \) to be calculated as well as the slope parameter \( dV_{S/10} \). The regression coefficients were then used to calculate expected values of blood lactate for each of the measured speeds using equation 3. This in turn enabled a Chi Squared Index of goodness of fit to be calculated using all of the data and allowing two degrees of freedom for each set of four observations and one degree of freedom for any sets of three observations. Determinations of the competition speed \( V_{comp} \) and the lactate level at this speed \( L_{comp} \) together with the relative power outputs \( P_T \) and \( P_{comp} \) gave rise to some difficulties for the following reasons:

a) Some swimmers did not have 400y or 400m freestyle competition times.

b) Not all those who did were actually capable of achieving the same performance level at the time of taking the profile.

c) Competition performances were over 400m and not 400y. Of all the 23 swimmers taking part there were 8 who either fell into category (a) or fell into the category (b) in the opinion of the Chief Coach. The difficulty posed by (c) was dealt with by using ASA Equivalent Performance tables to calculate the equivalent performance over 400 yards in a 33 1/3 yard pool. This was regarded as being the competition speed most appropriate for use with a lactate profile taken over that distance since it is a well known effect with lactate profiles that both the threshold speed \( V_T \) and the slope of the profile improve at shorter distances (6). The value of \( V_{comp} \) was thus determined for 15 swimmers and from it values of \( L_{comp} \) and \( P_{comp}/P_T \) were found. These data enabled the relative aerobic base and total anaerobic power contributions to be evaluated for each swimmer. By using the VOBLA speed \( V_{3.5} \) in place of \( V_{comp} \) in equation 7 it was also possible to calculate the relative aerobic base and total anaerobic power outputs at this speed for all swimmers.

Results

Goodness of Fit of Equation 3 to the Profiles

Using the data from all 23 swimmers to generate paired values of observed and expected lactate levels, a Chi
Squared value of 1.318 was obtained with a total of 39 degrees of freedom. Inspection of chi squared tables shows that the probability of this finding being due to chance is much less than 0.005. This was taken to indicate that equation 3 is an excellent fit to the lactate profile when speed $V > V_T$.

The Lactate Accumulation Threshold Velocity $V_T$.

The lactate accumulation threshold velocity $V_T$ was found to be different in male and female swimmers. The average values were: For the 9 male swimmers $V_T = 1.276 \pm 0.095$ (l.s.d.) m/sec and for the 14 female swimmers $V_T = 1.178 \pm 0.065$ (l.s.d.) m/sec. Application of Student’s $t$-test showed that the difference of $+ 9.8$ cm/sec was significant at the $p = 0.005$ level.

The Slope of the Rising Part of the Profile.

Values of $V_{5/10}$ were found for all swimmers and male and female results were arranged separately. No significant difference was found between the two groups. For male swimmers $dV_{5/10} = 0.070 \pm 0.026$ (at l.s.d.) m/sec and for female swimmers $dV_{5/10} = 0.067 \pm 0.023$ (at l.s.d.) m/sec

Lactate Levels Reached during Competition.

As stated previously the number of swimmers for whom it was possible to calculate reliable values was reduced for the reasons given. Results were available for 8 male and 7 female swimmers. Averages were found for 7 male and 7 female swimmers. The remaining male swimmer was atypical by comparison with the others in that he seemed to perform at very high lactate levels and according to his profile would have a blood lactate level of 25.6 mmol/litre at the end of his best recorded performances. Values for two groups of 7 are:

<table>
<thead>
<tr>
<th>Male Swimmers</th>
<th>$V_T$</th>
<th>$V_{T}^{3}$</th>
<th>$V_{comp}$</th>
<th>$V_{comp}^{3}$</th>
<th>Aerobic</th>
<th>Anaerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>1.360</td>
<td>2.515</td>
<td>1.536</td>
<td>3.624</td>
<td>69.4</td>
<td>30.6</td>
</tr>
<tr>
<td>RP</td>
<td>1.281</td>
<td>2.102</td>
<td>1.474</td>
<td>3.203</td>
<td>65.6</td>
<td>34.4</td>
</tr>
<tr>
<td>FB</td>
<td>1.301</td>
<td>2.202</td>
<td>1.483</td>
<td>3.262</td>
<td>67.5</td>
<td>32.5</td>
</tr>
<tr>
<td>JM</td>
<td>1.369</td>
<td>2.566</td>
<td>1.604</td>
<td>4.127</td>
<td>62.2</td>
<td>37.8</td>
</tr>
<tr>
<td>ML</td>
<td>1.303</td>
<td>2.212</td>
<td>1.523</td>
<td>3.533</td>
<td>62.6</td>
<td>37.4</td>
</tr>
<tr>
<td>CI</td>
<td>1.161</td>
<td>1.565</td>
<td>1.521</td>
<td>3.519</td>
<td>44.5</td>
<td>55.5</td>
</tr>
<tr>
<td>MJ</td>
<td>1.077</td>
<td>1.249</td>
<td>1.464</td>
<td>3.138</td>
<td>39.8</td>
<td>60.2</td>
</tr>
</tbody>
</table>

The swimmer BL with the exceptionally high estimate of competition lactate level had the figures:

<table>
<thead>
<tr>
<th>Female Swimmers</th>
<th>$V_T$</th>
<th>$V_{T}^{3}$</th>
<th>$V_{comp}$</th>
<th>$V_{comp}^{3}$</th>
<th>Aerobic</th>
<th>Anaerobic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non</td>
<td>1.244</td>
<td>1.925</td>
<td>1.598</td>
<td>4.081</td>
<td>47.2</td>
<td>52.8</td>
</tr>
<tr>
<td>LS</td>
<td>1.121</td>
<td>1.409</td>
<td>1.400</td>
<td>2.744</td>
<td>51.3</td>
<td>48.7</td>
</tr>
<tr>
<td>AS</td>
<td>1.250</td>
<td>1.953</td>
<td>1.471</td>
<td>3.183</td>
<td>61.4</td>
<td>38.6</td>
</tr>
<tr>
<td>KS</td>
<td>1.121</td>
<td>1.409</td>
<td>1.389</td>
<td>2.680</td>
<td>52.6</td>
<td>47.4</td>
</tr>
<tr>
<td>EC</td>
<td>1.092</td>
<td>1.302</td>
<td>1.400</td>
<td>2.744</td>
<td>47.4</td>
<td>52.6</td>
</tr>
<tr>
<td>SC</td>
<td>1.081</td>
<td>1.263</td>
<td>1.390</td>
<td>2.686</td>
<td>47.0</td>
<td>53.0</td>
</tr>
<tr>
<td>JS</td>
<td>1.167</td>
<td>1.589</td>
<td>1.400</td>
<td>2.744</td>
<td>57.9</td>
<td>42.1</td>
</tr>
</tbody>
</table>

Relative Aeroebic Base and Total Anaerobic Power Contributions during Competition Swimming.

Results were obtained for the same two groups of seven swimmers using equation (7). Full results are shown in Table 1 for both groups and for the male swimmer BL with the unusually high lactate levels. Average values for the percentage aerobic base contribution to the total power are:

- Male Swimmers: $58.8\% \pm 10.9$ [at l.s.d.]
- Female Swimmers: $52.1\% \pm 5.3$ [at l.s.d.]

As can be seen from the table there is considerable overlap with those two sets of results and the difference in the average values is not significant at the 10% probability level.

Relative Aeroebic Base and Total Anaerobic Power Contributions at VOBLA or $V_{3.5}$

These results did not depend on recent competition performances to indicate the current ability of the swimmer and were thus available for all swimmers taking part on the study. Average values for the aerobic base power contribution at this speed were:

- Male Swimmers: $72.6\% \pm 6.5$ [at l.s.d.]
- Female Swimmers: $74.1\% \pm 8.0$ [at l.s.d.]

Interestingly at this speed the aerobic base power contribution of the swimmer BL was 80.8\%.
Discussion

It has been suggested by some that blood lactate is not the best indicator of anaerobic metabolism (2). It could also be said that up to the present time, lactate samples have not been used in such a way as to clearly identify aerobic and anaerobic metabolic contributions to total energy production. We would suggest that the present study provides an easily accessible and clearly identifiable method of evaluating aerobic base and total anaerobic contributions to total power generation during swimming. The method distinguishes between the ability to swim fast aerobically without lactate accumulation and the ability to utilise anaerobic power when producing swims of high speeds. In addition to this the method allows positive identification of a swimmers strengths and weaknesses in the utilisation of energy. This means that a coach can accurately be advised as to the areas which require targeting to make training more productive.

Many different combinations of the relative utilisation of aerobic base and total anaerobic energy were found. Some swimmers had a very good value for $V_T$ but poor values of $dV_{5/10}$ and the ability to utilise anaerobic power during competition. By contrast there were other swimmers who had poor values for $V_T$ but good values for $dV_{5/10}$ and greater effectiveness when using anaerobic power.

Being able to balance the processes of aerobic energy production, lactic acid production and lactic acid clearance is a major physiological determinant of success in any sport. The improvement of lactic acid removal during exercise will result in only minor increases in blood lactate acid concentration despite a large increase in the rate of lactic acid production and this will increase the time that a swimmer can continue to swim at near maximum effort before fatigue sets in. These effects are well illustrated by comparison with the only swimmer in the group to reach international standard and another swimmer of the same sex who competed at the same distances but was unable to achieve the same level of performance.

Swimmer KM showed high values for all three parameters $V_{TM}, dV_{5/10}$ and anaerobic power utilisation. The other swimmer AS actually had a value for $V_T$ marginally higher than KM but had a much lower value for both $dV_{5/10}$ and anaerobic power utilisation. Consequently despite swimming to a lactic acid level nearly double that of KM, AS had a competition speed 8% slower. There are several factors which may contribute to this situation and which may differ between the swimmers. These will include differences in stroke mechanics and drag factors at higher speeds as well as differences in anaerobic power generation and lactic acid metabolism. Stroke mechanics can be compromised by increased fatigue which may be caused by greater muscle fibre recruitment and reduced fibre cycling while an increased use of large white fibre motor units may increase lactic acid production without a corresponding increase in clearance and oxidative metabolism. This may lead to a failure of the clearance mechanisms to keep pace with the production mechanism resulting in lactic acid accumulation and a rapid build up of hydrogen ions which in turn reduces muscle pH and therefore the ability of the muscle to contract with the required power to sustain swimming speed. This reduction in power is due to the fact that an increase in muscle cell acidity reduces the activity of the specific enzymes involved in the anaerobic pathway (7) and is probably the most overlooked aspect of the processes involved in muscle fatigue. The net effect is that the swimmer has a reduced ability to maintain a higher power output and loss of speed results. Bouissou (1) suggested that small but significant gains in performance can be made by increasing the peak of level lactic acid production as evidenced by the blood level. He suggested that by doubling the blood level of lactate, performance in competition might be increased by as much as 15%. This may be true if the ability of the swimmer to cope with the increased lactic acid production is improved so that the mechanics of the stroke are not compromised by stroke shortening, changing of body position, loss of streamline etc. We would suggest that the $dV 5/10$ values provide a useful assessment of the lactate tolerance ability of a swimmer. In the case of AS and KM one possibility is that although the aerobic base is the same in both swimmers a greater increase in lactate accumulation in AS results in a marked reduction in stroke efficiency. Training would require to focus on improving the swimmers ability to cope with lactate accumulation and its effects on the stroke as a whole. Our data showed that over this swimming distance $dV_{5/10}$ values were 0.068 m/sec on average (SD = ± 0.024 m/sec). This demonstrates an ability to increase speed in this lactic acid range by between 2.5% and 8.8% over the $V_{15}$ speeds. For larger increases in speeds a dramatic increase in blood lactic acid well above the 10 mmol/litre range would be necessary.

Maglischo (7), suggested that the relative contributions of the aerobic and anaerobic system in the 400m freestyle should be:

<table>
<thead>
<tr>
<th>ATP/CP</th>
<th>AEROBIC</th>
<th>ANAEROBIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>7%</td>
<td>40%</td>
<td>53%</td>
</tr>
</tbody>
</table>

As the ATP/CP pathway does not produce lactic acid it is viewed as part of the aerobic element of energy production for the purposes of this paper. Our results showed that only three swimmers met this suggested distribution of energy production, one of whom reached international standard. In relation to this it was noticed that the majority of male swimmers had a proportionately large aerobic contribution suggesting a large aerobic capacity. These swimmers would gain more speed from increasing their ability to use anaerobic pathway while maintaining the benefits of a large aerobic base.
Another swimmer (CI) showed a much greater reliance
an anaerobic metabolism with ability clearly geared
towards sprint events. His results suggest that, in order
to bring about improvement at distances of 100 m and
200 m it would be necessary to target both aerobic
development and the ability to control the accumulation
of lactic acid at and above the breakaway point.

An analysis of the relative power contributions at the
lactic acid breakaway point (VOBLA reference point
= 3.5 mmol/litre) showed that the average total
anaerobic power percentage % in males was 27.4% while
in females it was slightly lower at 25.9%. The differ-
ence between the two sets of values was not signifi-
cant at the 5% level of probability and there was a large
range in the values obtained. A similarly large range was
noted in the values of \( dV_{\text{max}} \) in both male and female
swimmers. This parameter is a direct indication of a
swimmer’s ability to deal with the increasing accumu-
lation of lactic acid. Average values were 0.070 m/sec
for males and 0.067 m/sec for females with once again
no significant difference between the two sets of results at
the 5% probability level. Thus the most striking feature
of these sets of results is not the relatively small differ-
ence between the means for the male and female groups but
the wide range of values encountered in both groups.
What this may indicate is a requirement to individu-
alisate training as far as possible if each swimmer is to develop
his or her ability to the optimal extent.

Conclusion

The method described in this paper demonstrates that
a great deal of information on performance charac-
teristics can be obtained from the observation of whole
blood lactic acid using a standardised sampling technique.
The mathematical model used is shown to be an excellent
fit to the observed data and when used in conjunction with
the relative power expenditure formula clearly identi-
fies the lactate accumulation threshold velocity and the
relative aerobic base and total anaerobic power contribu-
tions when swimming at any speed. A value is also iden-
tified for the lactate levels during competition. The identi-
fication of the lactate accumulation threshold speed is
an accurate and precise way of quantifying the current
level of the aerobic base. The ability to calculate the
relative power contribution of the aerobic base and total
anaerobic pathways and the maximal power output is
a useful tool for the monitoring of training progress and
identifying accurately where more emphasis may be
required.

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Firstly to Fred Furniss, the Chief Coach of the City of Sheffield
Swim Squad, for his keen interest in and support for this work. His
knowledge of his swimmers capabilities was quite remarkable with the
result that out of 92 timed swims one was not on the rising part of
the swimmers lactate profile and all swimmers had one swim very
close to the anaerobic threshold.

Secondly to Dr Clare Crofts, Sports and Exercise Science, Medical
Physies Department, who took the lactate samples and measured them
with commendable efficiency and promptness.

Also we would like to thank all those members of the Senior Na-
tional Squad who participated in the study and finally we would like
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Effects of Warm Down Techniques on the Removal of Lactate Acid Following Maximal Human Performance

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Abstract

The purpose of this study was to compare the effect of an active warm down with a passive warm down on the removal rate of lactic acid from the blood, in competitive swimmers following maximal exercise. Sixteen subjects (eight males and eight females) were randomly selected from a group of volunteers from a college swim team. Blood lactate levels were calculated for all subjects at rest, following maximal exercise, and twice during the prescribed warm down. All subjects displayed significantly elevated levels of blood lactate following maximal exercise. Both active and passive warm downs significantly decreased the level of post exercise blood lactate. The active warm down produced a significantly faster removal rate of blood lactate than the passive warm down. Based on the faster removal rate of blood lactate following maximal exercise, the active warm down is superior to the passive warm down when time is a variable.

Introduction

Competitive swimming has improved vastly on all levels within the last twenty years. The application of physiological principles to training and competition has enabled swimmers to improve their level of performance. An area of particular concern is the accumulation of lactic acid following competition or high intensity workouts.

Competitive swimming requires intense activity from large muscle mass along with restricted patterns of breathing. These requirements favor involvement of anaerobic energy release with the subsequent accumulation of lactate in the blood (19).

Swimmers competing in dual, invitational and championship meets often must swim multiple events within a brief time period. It is not uncommon for a swimmer to complete an individual event and then be a member of a relay within a thirty minute period.

Frequently following situations such as the one mentioned above, as well as after vigorous workouts, coaches hear complaints of muscular fatigue, soreness and exhaustion. Researchers (2,12,15,16) have looked at identified causes of these complaints. One identifying factor is an excessive accumulation of lactic acid remaining in the skeletal muscles and blood.

Studies, (2,10,12,15,18) have concluded that the presence of lactic acid in the skeletal muscle system will hinder the performance of athletes in competition. Lactic acid inhibits the mobilization of free fatty acids and retards the rate of glycolysis by inhibiting the activity of such enzymes as lactic dehydrogenase and phosphofructokinase. Lactic acid appears to cause muscular fatigue indirectly, by decreasing the intracellular pH of the muscle, slowing of the muscle's contractile rate and reducing the supply of energy for muscular contraction (8). The excessive accumulation of lactic acid in the muscle causes a burning pain that will cause a decrease in the speed of the swimmer (16). Therefore the removal of excess lactic acid between events becomes critical to both the coach and swimmer.

Naturally, coaches and athletes want to understand and determine the most effective way to alleviate the cumulative build up of lactic acid in the skeletal muscles. The ability to remove excess lactic acid from the muscles would increase swimmers' performance levels.

Warm down has been identified as the best way of eliminating the lactic acid in the muscles and blood system following a maximal performance (1,2,9,10,12,15,19). The warm down typically follows maximal or near maximal performances. It cools the body down, as well as stretches associated muscles. In addition, it helps reduce some of the lactic acid which has accumulated within the muscles during the activity. Removal will help reduce some of the pain and feeling of constriction in the muscles associated with the build up of lactic acid.
There are two common practices used by athletes following maximal or near maximal activity. One method is simply to rest. The athlete either sits or lays down. There is a complete cessation of activity. The other technique is to continue exercise at a significantly reduced intensity. Those two practices have been identified as either active or passive warm downs. Both methods will reduce lactic acid and the effects associated with excessive accumulation.

The passive warm down technique is defined as a cessation of activity all together, in the form of resting the body after a workout or competition. The person usually lies down with the hope that complete inactivity will reduce the resting energy requirements and thus “free” oxygen for the recovery process.

Active warm down is defined as a reduced level of activity after the workout or competition has been completed. It usually consists of a short period of exercise at a level of intensity lower than the initial activity. Active warm downs keep the heart rate elevated enough to maintain the blood flow in order to remove the lactic acid, but, not high enough to continue the production of the lactic acid which is associated with the anaerobic threshold. Submaximal aerobic exercise is performed in the belief that this continued movement will in some way prevent muscle cramps, stiffness and facilitate the recovery process. (2,12,17).

The purpose of this study was to compare the effect of an active warm down with a passive warm down (as defined previously) on competitive swimmers. The removal rate of lactic acid from the blood following strenuous exercise was the factor used to determine which form of warm down was more beneficial. More specifically, this study considered the following:

1) Will an active warm down have an effect on the removal of lactic acid from the blood following a maximal performance level?
2) Will passive warm down, consisting of a complete cessation of activity, have an effect on the removal of lactic acid from the blood following a maximal performance level?
3) Will swimmers who complete an active warm down display a faster removal of lactic acid compared to a passive warm down?
4) Will the amount of time and distance swam have an effect on the removal rate of lactic acid?

This study was significant because limited research has been completed comparing the influence of different warm down techniques on competitive swimmers. Furthermore, this study adds to the limited knowledge about warm down techniques for competitive swimmers.

Methods

The subjects consisted of eight collegiate male swimmers and eight collegiate female swimmers, ranging in age from 18 to 22, that were randomly selected from a group of volunteers solicited from the College of Wooster Swimming Team. All subjects competed in the North Coast Athletic Conference (NCAC) a Division III member, of the National Collegiate Athletic Association (NCAA), during the 1991-1992 season.

An orientation meeting was called with the subjects to provide details of the experimental procedures and an explanation of the risks involved. At the initial meeting, written consent forms were completed by all subjects. During the orientation, there was no mention of the hypothesis.

An initial lactate reading was taken on all subjects at resting conditions for the purpose of obtaining a base to which the elevated lactate levels could be compared.

For the purpose of this study, lactate was measured from a bead of blood drawn from a lancet prick of the middle finger of either hand and analyzed using the YSI model 23L lactate analyzer. All subjects were tested under both a passive and an active warm down situation. The experimental conditions were as follows:

1) A moderately hard warm down (active).
2) No activity at all following workout (passive).

The moderately hard warm down, consisted of two 500 yard freestyle swims at a 60% effort. The rest interval between the 500 yard swims was about 60 seconds in length (enough time to collect a sample). The passive warm down, consisted of sitting comfortably on the deck of the pool, immediately following the time trial or competition for 30 minutes.

All subjects were tested twice, at an invitational meet in January (exercise situation A) at which each individual swim no less than a 200 yard race and during a 400 yard (maximal effort) time trial (exercise situation B) seven days later. The passive warm down results were obtained from the invitational. Active warm down results were obtained from the 400 yard time trial. In both situations, the blood samples were taken from a dry finger directly after a maximal swim. Following the initial post competition sampling, subjects were instructed to complete the prescribed warm down. During the passive situation subjects rested on the deck and provided additional samples at 15 and 30 minutes. During the active warm down the subjects swam a 500 yard swim, provided a sample and then completed a second 500 yard swim followed by a second sampling. The entire active warm down process was completed in a period of 15 minutes or less.

A series of analysis of variance tests (ANOVA) and multiple analysis of variance tests (MANOVA) were computed to analyze the data and determine if any significant differences occurred. Significance was accepted at the .05 level.

Results

All of the subjects displayed elevated levels of blood
lactate following their maximal swims. Both warm down situations reduced blood lactate levels from post exercise efforts. The descriptive statistics for these groups are presented in Table 1.

Table 1. Descriptive statistics for warm down study

<table>
<thead>
<tr>
<th>Exercise Level</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting Level</td>
<td>1.35</td>
<td>.356</td>
<td>.9-2.3</td>
</tr>
<tr>
<td>Post Exercise A</td>
<td>7.53</td>
<td>1.67</td>
<td>4.1-9.9</td>
</tr>
<tr>
<td>Post Exercise B</td>
<td>6.863</td>
<td>1.95</td>
<td>3.8-10.6</td>
</tr>
<tr>
<td>Passive (15 mins.)</td>
<td>3.056</td>
<td>1.19</td>
<td>2.1-7.7</td>
</tr>
<tr>
<td>Passive (30 mins.)</td>
<td>3.05</td>
<td>1.19</td>
<td>1.2-4.9</td>
</tr>
<tr>
<td>Active (500 yards)</td>
<td>4.125</td>
<td>1.88</td>
<td>1.7-7.9</td>
</tr>
<tr>
<td>Active (1000 yards)</td>
<td>2.20</td>
<td>1.44</td>
<td>1.1-6.3</td>
</tr>
</tbody>
</table>

Values reported in millimoles per liter (mmol/l)

No significant difference in lactate levels was found between exercise situation A and exercise situation B, verifying that both situations (maximal efforts) produced similar lactate levels. Significant differences in lactate levels were found between resting (base) levels and exercise situations A and B (p < .0001), verifying that blood lactate levels did significantly increase following a competitive exercise.

A significant difference in lactate levels was found between exercise situation A levels and passive warm down levels, verifying that exercise situation A blood lactate levels did significantly decrease following both 15 (p < .01) and 30 (p < .0001) minute passive warm downs.

A significant difference in lactate levels was found between exercise situation B levels and active warm down levels, verifying that exercise situation B blood lactate levels did significantly decrease following both the 500 yard (p < .0001) and 1000 yard (p < .0001) warm down swims.

No significant difference was found between blood lactate levels following a 30 minute passive warm down and the 500 yard (active) warm down verifying that both situations produced similar reductions. A significant difference was found between the blood lactate levels following a 30 minute passive warm down and the second 500 yard swim, verifying that following the completion of a 1000 yard warm down swim, blood lactate levels were significantly lower for the subjects using an active warm down as compared to a passive warm down.

Discussion

It is documented that blood lactate levels increase during maximal exercise (2,7,10,11,12,15). Lactate levels increase in the muscle cell and correspondingly also in the blood during any high intensity athletic performance (15). This study used two methods to verify an increase in lactate levels due to exercise performance, a competitive swimming meet and a maximal effort time trial. As verified and supported in the results section, both types of swimming did significantly increase lactate levels beyond the resting level.

The results of this study support the thesis that an active warm down is more capable of removing lactic acid in the blood following a strenuous activity, compared to a passive warm down based on time as a factor. Jervell (13) showed that the blood lactate level could be made to fall faster, compared with resting conditions (passive), if moderate exercise was performed in the recovery period. This observation was later supported by other researchers and studies (2,10,12,15).

According to Belcastro & Bonen (1975), skeletal muscle blood flow increases with elevating exercise exertion, thus the transport of lactic acid to the removal sites during aerobic recovery exercise is facilitated. Lactic acid production must not occur when attempting to minimize the net concentration of lactic acid during the recovery period. Therefore, lactic acid removal should occur most effectively during moderate exercise recovery intensities, as this provides for conditions where a minimal amount of lactic acid is produced and skeletal muscle blood flow is increased to transport lactic acid to the liver and muscle where the removal occurs.

In this study, both active and passive methods produced a decrease in lactic acid levels in the blood following an elevated performance. Important to this study is the finding that all active recovery bouts removed lactic acid faster and more thoroughly than passive recovery rates based on time as a variable. The active warm down removed significantly greater amounts of lactic acid from the blood following 15 minutes (1000 yards) compared to 30 minutes of the passive warm down. This difference is of great significance for a swimmer that will compete in multiple times in one day. A swim meet, for example, often requires a swimmer to perform at peak levels numerous times in a period of time less than 30 minutes. In that case, an active warm down between events would be more beneficial to the swimmer than simply sitting or resting (passive).

Considering the effects of lactic acid on the body while trying to perform at optimal levels, coaches and swimmers must realize the importance of an active warm down following maximal or near maximal performance. Swimming a single 500 yard swim at a moderate level reduced blood lactate similar to resting for a period of 30 minutes. The completion of a second 500 yard swim produced reductions significantly greater than the 30 minute rest period. Active warm downs are warranted in swimming, as well as in many other competitive sport activities (1,2,9,12,15,19).

Conclusions

This study resulted in the following conclusions.

1) Intense exercise significantly increases the produc-
tion of lactic acid in the blood and muscles beyond resting levels.

2) Cessation of exercise for thirty minutes will significantly decrease the level of lactic acid in the blood.

3) An active warm down of a moderate 500 yard swim will significantly decrease the level of lactic acid in the blood from immediate post exercise levels.

4) An active warm down for a period of approximately fifteen minutes (1000 yard swim) will significantly decrease the level of lactic acid, beyond the level reached after thirty minutes of a passive warm down.

5) In this study an active warm down was superior to a passive warm down.

Acknowledgements
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References


Prescribing and Evaluating Interval Training Sets in Swimming: A Proposed Model

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Abstract

Swimming coaches rely heavily on interval training sets to develop various physiological capacities in their swimmers. This type of training is quite versatile since by manipulating the distance of the repetitions and the rest intervals, coaches can target sprint capacity, aerobic power, aerobic endurance, or lactate tolerance for improvement. The difficulty in using interval training that targets these physiological capacities, however, is that these sets produce different levels of adaptation stress that, if applied too frequently, may result in poor results or even an overtrained state. Consequently, it was felt that practical tools are needed to help coaches evaluate the relative degree of physiological stress associated with each of these types of interval sets. It is the purpose of this paper to introduce a suggested model for evaluating this stress. Furthermore, specific recommendations for constructing interval sets are also included.

Introduction

In the past 10 years, a great deal of attention has been focused on developing methods to prescribe appropriate training intensities for competitive swimmers. Even a cursory review of related literature suggests that most of the papers in this area focus on methods for establishing appropriate aerobic training paces. This is perhaps because most competitive swimmers perform large amounts of "aerobic" interval sets during their daily training and that unless appropriate paces are prescribed, some individuals may under-work while others may overwork. The obvious next step in this logic is that if all individuals are given appropriate intensity prescriptions, each swimmer has his/her greatest chance of reaping optimal training effects. The result should therefore be that a large percentage of the team will experience great improvements in performance while minimizing the chances of either under- or overtraining.

While these recent efforts to find valid and reliable aerobic intensity prescription methods are exciting and commendable, it is important to remember that the physiological requirements of competitive swimming are far more complex than simply improving one's aerobic capabilities. Optimal physiological performance in competitive swimming events requires that the individual possess the correct mix of aerobic endurance, aerobic power, lactate tolerance, and sprint ability. Consequently, the well-designed training program will incorporate strategies to improve these capacities in proportion to the demand of the events in which the swimmer specializes. Except for aerobic endurance, literature in coaching and in physiology is, however, relatively weak in describing tools that coaches can use to prescribe and evaluate interval training sets to target these specific adaptations. It is therefore the purpose of this paper to propose recommendations for designing interval training sets that specifically target aerobic endurance, aerobic power, lactate tolerance, and sprint ability. In addition, a system of evaluating the degree of physiological or adaptation stress associated with each type of interval training will be presented. It is hoped that these recommendations will offer the coach a way of objectively planning training that will maximize the swimmers' physiological adaptations.

Categories of Interval Training

That success in competitive swimming requires aerobic endurance, aerobic power, lactate tolerance, and sprint ability is supported both by research and by the logical extension of sound physiological principles that are based on the immediate physiological effects of swimming events (8). There is considerable evidence that each of these characteristics is in part genetic but can be altered by specific training regimens (4,10,11,12,13,15,16). Furthermore, each of these characteristics may require different intensities, duration of repeats, and rest intervals. Consequently, separate interval training sets should be designed to specifically target each of these desired adaptations.

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Sprint Ability

Sprint ability is conceptually the simplest of the four characteristics that will be discussed in this paper. This ability can be defined as one's maximum velocity and is apparently a function of muscle fiber type (5,6), level of creatine phosphate in muscle (1,9), activity of creatine kinase in muscle (10), maximum muscle power (16), and neuromuscular recruitment patterns (4). Related to sprint ability are other characteristics such as a person's ability to reach maximum velocity as soon as possible in the race, the ability to maintain maximum velocity for as long as possible, and the ability to call upon sprint ability in the middle and at the end of longer (> 30 sec) races.

Lactate Tolerance

At all intensities of swimming, the working muscles produce lactic acid because of incomplete oxidation of carbohydrate. When lactic acid is formed in the muscle, it immediately splits into lactate plus a hydrogen ion (H+). pH is a measure of the amount of H+ in the body fluids and when the H+ are allowed to accumulate in muscle, its pH begins to drop from a normal resting level of 7.0 down to about 6.3 at the lowest. A decreasing pH then can cause muscle weakness, tightness, and inability to continue contracting at high force. At very low swimming intensities (paces corresponding approximately to that which most swimmers would use in a 3,000 yard swim and slower), the rate at which lactate is produced can be balanced by the rate at which lactate is removed from the muscle and blood. Thus, no net accumulation of lactate or H+ occurs. At faster speeds, however, the breakdown of carbohydrate for energy by muscle is greatly accelerated and causes the production of lactate to outrun the lactate-removal mechanisms. Consequently, lactate accumulates in muscle and blood, and the pH begins to decline causing progressive develop of muscle weakness (fatigue). This is very likely what happens during a 200 yard race in which the swimmer starts the race at an excessive pace and is forced into a slower pace over the second half of the race.

Despite the rapid production of lactic acid, muscle lactate levels can increase up to about 4-5 times resting levels before the muscle's pH drops appreciably. This is because of buffers available within the muscle that bind the H+ and thereby remove them from solution. These buffers include substances such as bicarbonate, protein, and creatine phosphate. Muscles with high concentrations of these buffer substances are therefore capable of accumulating more lactate before the pH causes a fatiguing effect. These muscles are said to have a high buffer capacity or high lactate tolerance. Fast twitch muscle fibers have a greater buffer capacity than slow twitch muscle fibers, and although a person's muscle fiber type cannot be changed significantly by training, the buffer capacity of his/her muscles can be improved by training (15). Improved muscle buffer capacity and other indices of lactate tolerance (such as psychological tolerance of the pain associated with decreased muscle and blood pH) can, therefore, improve performance in any exercise that is limited by the accumulation of lactate (nearly all swimming events).

Aerobic Power

Aerobic power is measured as a person's maximum ability to consume oxygen. Endurance performance is determined in part by a person's aerobic power which serves as the upper limit or ceiling for aerobic endurance. There is considerable evidence that aerobic power of elite endurance athletes is far above that of the general population (2,14) and the longer the duration of competition, the higher the aerobic power of the top athletes is. However, within the population of elite athletes in a given sport, aerobic power does not have a very high correlation with their performance. Thus, it seems that high aerobic power is necessary to become elite in endurance sporting events, but once this capacity is fully developed, other characteristics decide the order of finish. One such physiological characteristic that is more closely correlated with endurance performance is aerobic endurance (3,7).

Aerobic Endurance

Aerobic endurance is a measure of one's ability to perform prolonged, continuous exercise and depends on many physiological, biomechanical, nutritional, and psychological factors. The most recent measure thought to best represent aerobic endurance is the lactate threshold or anaerobic threshold. Simply stated, such a test measures the maximum speed a swimmer can sustain without experiencing progressive accumulation of lactate in blood. An easy way to estimate this pace is to swim a 2000 yard time for time and convert the seconds per 100 yards, or to swim for 30 minutes and record the distance swum and convert to pace per 100 yards. Obviously, the faster a person can swim without accumulating lactate, the better their performance will be in longer events (> 100 yards).

Some coaches and scientists question the specificity of aerobic endurance for competitive swimming because the longest race lasts only approximately 15-20 minutes, depending on the swimmer's performance ability. Clearly, aerobic endurance is important in this type of event, but most of the swimming races last only 1-2 minutes and are swum at speeds far greater than the speed at lactate threshold. There are perhaps two reasons to justify aerobic endurance training for swimmers who do not compete in events lasting more than 10 minutes. First, the physiological stress involved in performing daily or twice per day competitive swim training requires rapid recovery capabilities from swimmers. Because aerobic endurance training seems to facilitate the recovery pro-
cesses, swimmers may need this type of training adaptation simply to be able to tolerate the demands of lactate tolerance, aerobic power, and speed training. Second, aerobic endurance training may be the easiest and most efficient way of improving a swimmers economy (i.e., most energy efficient stroke mechanics for a particular swimmer). If economy is improved, then the swimmer can swim at faster speeds before reaching lactate threshold, and at race paces, will not exceed their lactate threshold pace by as great a margin as if they had low economy.

**Designing Interval Training Sets**

Because adaptations to training are so specific to the type of training used, each of the preceding types of training requires different types of training sets to elicit the desired adaptations. Furthermore, it is unreasonable to assume that any one form of training can optimally or even adequately stimulate adaptations in sprint, lactate tolerance, aerobic power, and aerobic endurance. Consequently, a well designed and comprehensive training program for competitive swimmers will include a mixture of the types of training that is matched to physiological needs dictated by the events in which the swimmer specializes. Part of the coach's responsibility, then, is to design appropriate interval training sets that target specific adaptations, and to distribute these sets over several weeks, months, and even years during a swimmer's career.

Every interval training set should consist of a prescribed number of repetitions, distance or time of each repetition, amount of rest allowed between each repetition, and intensity of the efforts. By adjusting one or more of these parameters, coaches can effectively target any one of the four previously described forms of training. Table 1 contains the recommended ranges for total time of work in the set (sum of repetition times), amount of rest to allow between each repeat (can be active or passive), duration of each repetition, and appropriate intensity of the efforts.

**Table 1. Recommendations for constructing interval training sets.**

<table>
<thead>
<tr>
<th>AE</th>
<th>AP</th>
<th>LaTol</th>
<th>Sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>12-60 min</td>
<td>10-30 min</td>
<td>4-15 min</td>
</tr>
<tr>
<td>Rep time</td>
<td>1-20 min</td>
<td>1-3 min</td>
<td>30 sec-2 min</td>
</tr>
<tr>
<td>Rest interval 10 sec-1 min</td>
<td>rep x 0.5</td>
<td>rep x 2-3</td>
<td>rep x 6-10</td>
</tr>
<tr>
<td>Intensity</td>
<td>70-80%</td>
<td>80-90%</td>
<td>&gt; 85%</td>
</tr>
<tr>
<td>HRmax</td>
<td>HRmax</td>
<td>HRmax</td>
<td></td>
</tr>
</tbody>
</table>

AE - Aerobic Endurance, AP - Aerobic Power, LaTol - Lactate Tolerance Rep time - swim time for each repetition in interval set, HRmax - maximum heart rate, Stress Index - relative degree of physiological stress (to be multiplied by total swim time in set to yield stress score for the interval set).

To use these recommendations, the coach should first decide on which type of set to construct then pick a distance that will result in a repeat time within the recommended range. Once the repeat time is established, the coach can divide the recommended total time by the repeat time to calculate the number of repetitions. Then the coach would specify an appropriate rest interval and intensity within the recommended ranges for the type of set that was constructed.

Sprint sets, for example, should total 2-5 minutes of sprint swimming time with each repetition lasting less than 30 sec. Therefore, repeated 25 yard sprints would be appropriate. Since each sprint will last approximately 15 seconds, the number of repeats will need to be between 8 and 20 (2 min divided by 15 sec = 8 reps; 5 min divided by 15 sec = 20 reps). Because the duration of each repetition in this example is close to the recommended upper limit for duration, the number of repetitions should probably remain fairly close to the recommended lower limit (i.e., 10 repeats). Thus, the interval training set is 10 x 25 yard sprints at maximum velocity. Because rest interval is recommended to be between 6 and 10 times as long as each repeat, the swimmers should get between 1.5 and 2.5 minutes recovery time. Although this may seem to some coaches an extraordinarily long rest interval, research shows that it takes at least 1.5 minutes for complete repedition of muscular stores of creatine phosphate after having been depleted by a prior sprint (9). If insufficient rest is allowed, the swimmers will not completely recover their creatine phosphate levels, and therefore may not be able to reach top speeds on subsequent repeats. In addition, there is some evidence that if the muscle creatine phosphate stores are not allowed to recover between sprints, subsequent swims may require greater lactate production. If this occurred, the remainder of the set would be one that should be considered as a lactate tolerance set rather than a sprint set. Coaches can determine if a sprint set is allowing enough rest by simply measuring their athletes' repeat times to make sure they are sustaining a sprint effort through the whole set and are neither slowing during the second half of the set or are not overly pacing themselves to prevent slowing on later repeats.

**Estimating Physiological Stress of Interval Sets**

Although all four forms of training are probably required for optimal physiological improvement of swimmers, including several of these sets from each form of training in each practice session over a week or more would likely over stress even the most work-tolerant swimmer and eventually lead to chronic fatigue and possibly
an overtraining state. Consequently, each practice session probably should consist of only one or two main interval sets with warmup, stroke drills, kicking drills, and instruction. During this practice session, the two main interval sets may be an aerobic endurance set and a lactate tolerance set, for example. During the next practice session, the main sets may be aerobic endurance and a sprint set. By alternating between the different forms of training from practice to practice over several weeks, the swimmers can be repeatedly exposed to the specific forms of training desired while minimizing the chances of overtraining.

Some coaches, however, feel the need to quantify the work that has been done in various types of training. Most often, the total yardage performed is used as an estimate, but unfortunately, yardage is not a fair reflection of the physiological stress associated with the different forms of training. For example, 800 yd of aerobic endurance work can be tolerated by most swimmers with very little depletion of muscle glycogen and virtually no residual fatigue or muscle soreness. On the other hand, 800 yards of lactate tolerance training can cause some muscle soreness and damage, can increase muscle protein breakdown, and would certainly drain more glycogen from muscle than would 800 yd of aerobic endurance training. Consequently, the physiological intensity of the training set must be considered along with the time or distance covered by the sets in order to evaluate the total adaptation stress of the practice session and to estimate how this total is distributed among the various forms of training.

Table 2 contains a proposed method of evaluating training stress that accounts for both the physiological intensity and the duration of the sets. This method is based on index scores assigned to each type of interval set that reflect the relative amount of physiological stress or intensity of each set type. This index score is then multiplied by the total time of work within the set to estimate the total adaptation stress associated with the set. For example, consider the following aerobic power set:

6 x 200 / 2 min rest @ 85% HRmax

Since it is an aerobic power set, the index score is 6. Multiplied by the total work time of 13 minutes (2:10x5), the total stress in this set is estimated at 78. The recommended range of total stress for each of the interval training types is also shown in Table 2 and can be used to determine if a particular set has been constructed correctly.

**Allocation of Adaptation Stress**

To evaluate or plan the relative emphasis on the different forms of training, total stress scores in each form of training should be recorded for each training day and then totaled by week. In any one week of training, there will likely be several interval training sets from each form of training and by totalling the stress separately for aerobic power sets, lactate tolerance sets, sprint sets, and aerobic endurance sets, the coach can retrospectively evaluate the degree of emphasis placed on particular adaptations on a weekly basis. Alternatively, the coach can plan training by deciding ahead of time which type of training to emphasize and to what extent the types of training should be emphasized during the coming weeks. For example, a coach may wish to plan a week in which the total adaptation stress is 700 with a fairly important meet scheduled for the weekend. Within this week the coach may want a fairly heavy aerobic day on Monday, followed by a lactate tolerance day on Tuesday, another longer aerobic day on Wednesday, with some sprinting on Thursday while at the same time tapering down slightly for the weekend meet. Accordingly, the coach may allocate daily stress during the week in the pattern shown in Table 3.

<table>
<thead>
<tr>
<th>Table 2. Stress scores for the different types of interval training.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>Stress Index X</td>
</tr>
<tr>
<td>Work Time (min)</td>
</tr>
<tr>
<td>Stress Score</td>
</tr>
</tbody>
</table>

AE-Aerobic Endurance, AP-Aerobic Power
LaTol-Lactate Tolerance

<table>
<thead>
<tr>
<th>Table 3. Stress scores and % emphasis in each type of training for one week of training.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
</tr>
<tr>
<td>Tuesday</td>
</tr>
<tr>
<td>Wednesday</td>
</tr>
<tr>
<td>Thursday</td>
</tr>
<tr>
<td>Friday</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>% Emphasis</td>
</tr>
</tbody>
</table>

AE-Aerobic Endurance, AP-Aerobic Power
LaTol-Lactate Tolerance

Calculations of stress scores for each form of training reveal that during this sample week of training, 63% of the physiological stress was allocated to aerobic endurance training, 10% to aerobic power training, 20% to lactate tolerance training, and 7% to sprint training.
Depending on the swimmers' performance at the weekend competition following this training week, the coach may wish to consider allocating stress differently for future weekend meets. With records such as this, the coach could make very specific adjustments to training in an effort to find the ideal mix and sequence of training for their swimmers. It can be argued, however, that the same objectives can be accomplished by merely keeping track of the amount of yards or meters devoted to each form of training. Unfortunately, however, distance devoted to various forms of training does not provide a relative comparison of the amount of adaptation stress associated with the forms of training. For example, if the interval sets that were used in the training week shown in Table 3 are evaluated based on the number of yards devoted to each form of training, the results would appear as in Table 4. The row labelled "% emphasis" shows that 83% of the yardage was in aerobic endurance training, 4% in aerobic power training, 8% in lactate tolerance training, and 4% in sprint training. Because there is such an apparently high emphasis on aerobic endurance training and such a low yardage emphasis on the more stressful forms of training (aerobic power and lactate tolerance training in particular), the coach may underestimate the amount of stress his or her swimmers may experience during this week.

Table 4. Yardage and % emphasis devoted to each type of training during one week of training.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>AE</th>
<th>AP</th>
<th>LaTol</th>
<th>Sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>6,200</td>
<td>5,000</td>
<td>1,000</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Tuesday</td>
<td>3,400</td>
<td>2,200</td>
<td>1,200</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wednesday</td>
<td>7,200</td>
<td>7,000</td>
<td>0</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Thursday</td>
<td>2,500</td>
<td>1,600</td>
<td>500</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Friday</td>
<td>3,200</td>
<td>3,000</td>
<td>0</td>
<td>0</td>
<td>200</td>
</tr>
</tbody>
</table>

* AE-Aerobic Endurance, AP-Aerobic Power, LaTol-Lactate Tolerance

% Emphasis

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>4</th>
<th>8</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>22,500</td>
<td>18,800</td>
<td>1,000</td>
<td>1,700</td>
</tr>
</tbody>
</table>

Conclusion

There should be little argument that coaches should consider the relative amount of stress associated with each form of training in designing and evaluating their training. Categories of training, constructed to represent varied amounts and types of adaptations stress were proposed in this paper. Furthermore, a relative stress scoring system was also proposed. The advantage of calculating and recording stress scores for interval training are that this may provide coaches a practical and more valid method for planning and evaluating training than yardage. Coaches could then use this approach to experiment with different mixtures and sequences of training within one training week, month, or season. In addition, various strategies for tapering could be studied such as whether it is better to taper all forms of training equally or to taper more in lactate tolerance while keeping the aerobic endurance adaptation stress relatively constant. It is hoped that such experiments will be conducted both by coaches and in laboratory settings to help refine this approach to training.

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