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The Results of Administering a Modified "Two-Point" Lactate Profile Test on Swimmers for Two Successive Indoor Swimming Seasons

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Abstract

An average of forty competitive swimmers were tested once each month for seven months, October to April, for two successive indoor swimming seasons. A modified lactate profile test was administered on each swimmer during the last week of each calendar month. The test consisted of two 200 yard swims, the first at 100% effort and the second at 90% effort, based on the first swim. Blood lactate samples were taken after each swim. Lactate concentrations vs. swimming velocities were plotted for each subject. The relative changes in position of the curve was tabulated. Early to mid-season responses indicated an increasing aerobic adaptation to the training. Evidence for this change was the shifting, between successive tests, of the monthly lactate curve in a direction "downward and to the right". A significant number of subjects (P < 0.05) demonstrated this trend between the months of November and December of each season. Progression of the lactate curves appeared variable when observed during the balance of the training period. A post-season test, three weeks after the last major competition, provided evidence of a pronounced detraining effect. This was demonstrated by significantly increased blood lactate concentrations with corresponding reductions in swimming velocities. (P < 0.01). Ratios of blood lactate concentrations to swimming velocities at 100% effort were compared between subjects categorized according to stroke and race distance. Significant differences (P < 0.05) were found in the ratios of swimmers specializing in the distance events in comparison to those categorized as sprinters and middle-distance swimmers. The differences in the ratios for subjects when grouped by stroke were not statistically significantly. The findings of the study illustrate the variability among swimmers in aerobic and anaerobic adaptations to training during the course of a training season.

Introduction

The monitoring of changes in blood lactic acid continues to be used as a means of assessing the effects of training of elite athletes (2,3). Simplification of data collection has resulted in increased adoption of this form of testing in competitive swimming. One of the earliest tests to be adopted was the "two-point" lactate profile test which requires blood lactate samples to be drawn following two successive swimming efforts each of which is performed at a fixed work intensity (4, 5, 6, 7, 9, 10).

Studies using this protocol have reported results that reflect aerobic adaptations during periods of intensive swimming training (4,5,9,10). Although these studies have examined the results of repeated tests, information on the manner in which blood lactate profiles change during the course of a competitive swimming season is limited. Consequently, the intent of this study was to examine the changes in lactic acid profiles in swimmers during two indoor swimming seasons. A post-season profile was conducted in the first of the two seasons to assess the effects of detraining on these profiles.

Methods

Experimental design. The study was conducted over two consecutive indoor swimming seasons. Indoor swimming seasons in the United State traditionally extend from late September to mid-April. For the study, the first testing period was from October 1985 to April 1986, the second period from November 1986 to April 1987. Tests were conducted during the last week of each calendar
month, and approximately three weeks after each subject's final competition for the season. A total of six tests were conducted in the first season's testing, and five tests during the second season.

A total of forty (40) swimmers participated in the study. Of this number, twenty-six swimmers were tested during the first season and twenty-seven were tested in the 1986/87 season. Thirteen (13) of the subjects participated in both seasons' testing. Of the total number, thirty-one swimmers were male and 9 swimmers were female. The swimmers ranged in age from 14 to 23 years and had participated in competitive swimming for a minimum of five years prior to the study. Subject characteristics are presented in Table 1. Their ability level ranged from State and Junior National qualifiers to U.S. Senior National Championship finalists. Subjects were required to perform all tests using their "primary stroke".

The lactate profile test used was modified from that described by Mader (4). A warm-up period consisting of a total of 2,000 yards, preceded each test. The test consisted of two 200 yard swims, the first at 100% effort, the second swim at a pace corresponding to 90% of the velocity of the first effort. The total rest period between the two trials was 15 minutes to allow lactate levels to return to near resting levels. The 100% effort was conducted first so as to provide a more accurate basis for prescribing the 90% effort. Following the 100% effort, 50 microliters of arterialized blood were drawn from the fingertip using heparinized tubules. A second sample was taken at the conclusion of the 90% effort. All samples were drawn between 3 and 5 minutes following each effort. The samples were mixed with a lysing/preservative solution and stored for analysis. The samples were analyzed in duplicate using a Model 231 Lactate Analyser (Yellow Springs Instrument Co.).

Performance times were converted to mean velocities (meters/second) and plotted on an x,y coordinate graph with lactate concentration on the ordinate and swimming velocity on the abscissa. A straight line was drawn between the two data points for each test, with successive tests plotted on the same graph to allow for comparisons between tests.

In order to assess the effects of training on blood lactate concentrations, two parameters were examined from the accumulated data. The directions of movement of each curve on the graph, relative to the position of the curve generated from the previous test was noted. Comparisons were made based on movement of the lactate curve shifting "downward and to the right" (D/R). This would be shown in the graphs as an increase in the values for the x-coordinate combined with decrease in values on the y-coordinate for each of the two data points. Movement in the curves "upward and to the left" (U/L), would be seen on the graph as decreasing values on the x-coordinate combined with increasing values on the y-coordinate (U/L). In addition, a comparison was made of the differences in blood lactate concentrations between subjects when grouped according to their primary stroke and distance. For this the ratios of blood lactate concentrations to the corresponding swimming velocities at 100% effort (HLa100% / Velocity100%) was used. Subjects whose primary race distance was 50 and 100 yards were classified as sprinters; those whose primary events were 200 and 500 yards were classified as middle-distance and swimmers specializing in the 1,650 yard event were placed in the distance category. Since the study was conducted in conjunction with on-going training, the total number of swimmers tested at each session varied. A summary of subject grouping and group sizes is presented in Table 1.

<table>
<thead>
<tr>
<th>Subject Characteristics including Stroke and Distance</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Freestyle</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Backstroke</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Breaststroke</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Age (yr)</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Butterfly</td>
</tr>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Age (yr)</td>
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<td></td>
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</tbody>
</table>

Values are mean ± SE.

The probability of the differences between the shifts of the lactate curves being due to sampling error alone was estimated by the normal approximation to the binomial distribution. To examine the differences in lactate production between subjects specializing in different strokes and competitive distances, the ratio of lactate concentration to swimming velocity at the 100% effort over the test distance was compared between groups. Group means were determined for each of the testing periods and analyzed for significance with a two-way analysis of variance (ANOVA). The level of probability necessary to reject the null hypothesis was set at P < 0.05.

Results
The monitoring of the relative changes in the positions of the lactate curve for each subject provided informa-
tion on the manner in which the lactate responses changed over the period of each competitive season. Comparisons were made of the ratios of the lactate values at the 100% effort to the corresponding swimming velocities for swimmers grouped according to their specialty strokes and distances.

Shifts of the lactate curve over repeated tests. The relative changes in the positions of the lactate curves for each subject were monitored for each test. Movement of the curve, downward and to the right (D/R) of the graph was tabulated and compared to movements of the curve in the opposite direction, i.e., upward and to the left (U/L). A small number of subjects showed increases in lactate values without decreases in swimming velocities during certain test periods. In these instances, the movement of the curve was categorized as U/L. Data for all subjects tested were combined to provide a composite for movements of the lactate curves between each successive testing period. Subject data were first combined for each of the two years of testing followed by a combined total for all subjects for both years. The resulting data for all tabulations is provided in Table 2.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Relative change in positions of lactate profile curves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>85/86 Season</td>
</tr>
<tr>
<td></td>
<td>D/R</td>
</tr>
<tr>
<td>Oct-Nov.</td>
<td></td>
</tr>
<tr>
<td>Nov.-Dec.</td>
<td>17</td>
</tr>
<tr>
<td>z = 2.84</td>
<td>p &lt; 0.01 *</td>
</tr>
<tr>
<td>Dec.-Jan.</td>
<td>17</td>
</tr>
<tr>
<td>z = 2.56</td>
<td>p &lt; 0.05 *</td>
</tr>
<tr>
<td>Jan.-Feb.</td>
<td>11</td>
</tr>
<tr>
<td>z = 0.94</td>
<td>p &lt; 0.60</td>
</tr>
<tr>
<td>Feb.-Post.</td>
<td>1</td>
</tr>
<tr>
<td>z = 3.21</td>
<td>p &lt; 0.01 *</td>
</tr>
</tbody>
</table>

D/R—Lactate curve moving downward and to the right of graph. U/L—Lactate curve moving upward and to the left of graph.
* Significantly different from previous months position.

The results of the two-tailed “z-test” provided the following information for the 85/86 season. Between the first and second month’s tests, i.e., from October to November, an equal number of swimmers, 10 in each group, demonstrated movement of their lactate curves in both directions. For the period between November and December, 17 swimmers demonstrated movement of the curve in the direction D/R in comparison to 4 who showed the opposite trend, U/L. This difference was significant (P < 0.01). Between December and January a similar number, 17 swimmers, had lactate curves which moved in the direction D/R, while 5 were in the direction U/L, which was also statistically significant, (P < 0.05). Between January and February, 11 swimmers were recorded in the direction D/R and 7 in direction U/L. For the post-seasonal test, taken 3 weeks after the last major competition, only 1 swimmer showed movement of the lactate curve in the direction D/R in comparison to 13 swimmers whose lactate curves moved in the direction U/L. As expected, this reversal in the direction of the movements of the curves was significant (P < 0.01).

For the 86/87 swimming season, testing commenced in November. For the month between November and December, 13 swimmers had lactate curves moving in the direction D/R and 10 swimmers in the direction U/L. Between December and January 13 swimmers moved in the direction D/R and 12 swimmers in the direction U/L. Between January and February, 12 swimmers moved in the direction D/R and 9 swimmers demonstrated movements in direction U/L. No post-seasonal test was administered at the conclusion of this season.

When data for both years of testing were combined, the following probabilities were shown. Between the months of November and December, a total of 30 subjects had lactate curves moving the direction D/R, in comparison to 14 swimmers whose curves shifted in the opposite direction. This difference was significant (P < 0.05). Between December and January, the combined totals for D/R was 30 and U/L was 17. Between January and February the totals were 23 for the direction D/R and 16 in the direction U/L. The combined totals for the period between February and the Post-season test reflect the same number as that for the 85/86 season, i.e., 1 in the direction D/R and 13 in the opposite direction. This difference being significant, (P < .01).

Lactate/Velocity ratios. For the first season of testing there was no significant difference between the mean ratios for subjects when divided into the swimming stroke categories. The mean ratio for Freestyle was 4.59 (n = 14), for Backstroke 5.12 (n = 2), Breaststroke 5.28 (n = 5) and Butterfly 5.18 (n = 5). However, when the subjects were grouped according to event distances a two-way analysis of variance showed a significant difference in the mean ratios for subjects categorized as distance swimmers in comparison to subjects categorizes as sprinters and middle-distance swimmers, (F = 4.104, P < 0.04). The mean ratio for the subjects in the distance group was 3.56 (n = 4) while the mean ratios for the sprinters and middle-distance swimmers were 5.16 (n = 12) and 5.07 (n = 10) respectively. In the second season of testing, the mean ratios for subjects divided by stroke were 4.16 (n = 15) for Freestyle; 5.02 (n = 3), for Backstroke; 5.39 (n = 6), for Breaststroke and 5.00 (n = 3) for the group swimming Butterfly. No significance was noted between these groups. The mean ratios for the subjects grouped according to event distances provided the following values. The
mean ratio for the sprinters was 5.03 (n = 13), for middle-
distance swimmers it was 4.42 (n = 11) and for the
distance swimmers the mean ratio was 3.62 (n = 3). 
Results are presented in Table 3.

Table 3
Means of Lactate/Velocities Ratios (Group Size).

<table>
<thead>
<tr>
<th></th>
<th>1985/86 Season</th>
<th>1986/87 Season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freestyle</td>
<td>Backstroke</td>
</tr>
<tr>
<td>Mean ratios</td>
<td>4.59 (14)</td>
<td>5.12 (2)</td>
</tr>
<tr>
<td>Mean ratios</td>
<td>5.16 (2)</td>
<td>5.07 (10)</td>
</tr>
</tbody>
</table>

*Significantly different (p<0.05) from other two distance groups.

Discussion

Lactate profile curves continue to be used in competitive 
swimming training to assess the changes induced by varied 
workloads. Since it has been customary to plot these 
curves based on two or more trials at a fixed 
distance, the manner in which these curves fluctuate over 
repeated tests is used to monitor metabolic adaptations 
(4, 5, 6, 9, 10). The relative changes in position of the 
curve are used as indicators of adaptations to the aerobic 
component of training if higher swimming velocities are 
accompanied by either the same or lower blood lactate 
values (4, 5, 6, 10). In this case, with each successive test, 
the curve would be seen as shifting “downward and to the 
right.”

The results of this study indicated that although there 
was evidence for the acquisition of aerobic capacity as 
reflected by movements of the lactate curve, this change 
was not consistent throughout the course of a training 
season. The combined data for the two years of testing 
presented in Fig. 1., indicates monthly variations in the 
total number of subjects whose lactate curves shifted in 
either direction. Between the months of October and 
November, of the 20 subjects tested, an equal number 
had changes in either direction. Since formal swimming 
training for the indoor season customarily commences 
in early October, the data demonstrating that an equal 
number of subjects showed movement of the curves in 
either direction could be attributed to subject variability 
in the rate at which they acquired aerobic conditioning. 
Between the months of November and December, a signi-
ficant number of subjects, 30 vs 14, demonstrated a 
higher swimming velocity accompanied by lower lactate 
values (P < 0.05). Figure 2 illustrated the lactate profile 
curves of a male distance swimmer showing typical 
aerobic adaptations for the first three months of the 
season as reflected by movement of the curves between 
October and December. This data is consistent with a 
study by Sharp (10) who reported the greatest degree of 
change of the lactate curve towards the right occurred 
during the first two months of the season. Since major 
emphasis is placed on building an aerobic based during 
this period of training, these changes in position of the 
curves are expected. The period between December and 
January continued to show similar trends. Although not 
statistically significant (P < 0.06), the calculated prob-
ability for this period the results reflect continued em-
phasis on aerobic conditioning as part of the training 
regimen. This is not unexpected since in spite of “mid-
season” and “dual-meet” competition during this period, 
the training still incorporated “workout sets” which are
designed for developing aerobic capacity. The final phase of the indoor training season begins in mid-January and continues until the introduction of the "taper," which customarily starts in late February. The emphasis during these weeks is on developing speed and the reliance on anaerobic power, a condition which may result in the decrease or reversal of aerobic adaptations. With the exceptions of swimmers specializing in "distance" events, lactate curves can be expected to reflect this shift in training. The final period between tests included the "taper", the week of major competition and the post-competitive period. During most of this time, the volume of swimming is reduced dramatically with emphasis placed primarily on work bouts of brief, high intensity. During the period following the last major competition, swimmers traditionally do no formal swimming training. For the subjects tested during this final phase, a significant number (P < 0.01), showed decreased aerobic adaptations as reflected by movements of the lactate/velocity curve upward and to the left. This reversal in position of the curve is illustrated in Fig. 3. A study on "detraining" competitive swimming. In contrast, when the subjects were categorized according to their competitive distances, a significant difference was seen in the mean lactate to velocity ratios during the first season of testing. The swimmers specializing in "distance" events had a significantly lower mean ratio (P < 0.04), in comparison to the "sprinters" and "middle-distance" swimmers.

Although the difference was not statistically significant (P > 0.05), for the second season of testing, the mean ratio for distance swimmers was the lowest of the three distances. These findings suggest that differences exist among trained swimmers in the ability to produce high concentration of lactic acid at maximal work bouts of less than 2 minutes in duration. These differences are based on groups categorized according to competitive swimming distances.

**Summary**

The study demonstrated that although changes in lactic acid metabolism are induced by intensive swimming training, the manner in which these changes occur are dependent on the quality and quantity of the training workloads. Variations in the relative positions of the lactate curves may be explained on the basis of the type of training that is being emphasized at each phase of the season's training. Comparisons of swimmers' blood lactate concentrations as a function of their ability to perform an "all-out" effort over 200 yards indicated differences based on event distances. Whether these differences between "distance swimmers" and those categorized as "sprinters" and "middle-distance" swimmers was due to metabolic adaptations resulting from the imposed training regimen or natural selection based on a predisposition to endurance-type events, or a combination of these two factors, cannot be determined from this study.

![Figure 3. Lactate profile of a single subject (18 year-old, male, middle-distance freestyler) for one swimming season. Curve generated for "post-season" test reflects characteristic detraining effect.](image)

**References**

Validation of a Criterion Measure for Swimming Technique

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Abstract
A technique variable (EHB) was theoretically developed to assess swimming technique. Differential hand pressure measurements were combined with the displacement of the body to determine the effective hand distance with respect to the body (EHB). The problem of the study was to determine the validity of EHB as a criterion measure for swimming technique. If EHB is a valid measure of technique, then in addition to being reliable, the value of EHB would be greater: 1) for competitive swimmers than for recreational swimmers, 2) for an experimental group treated with instructional cues designed to increase EHB than for a control group exposed to a benign treatment, and 3) after being coached with instructional cues designed to increase EHB than before.

Three experiments were conducted to establish the reliability and relevance of EHB as a criterion measure. The technique analysis system (U.S. Patent 4,654,010) is a computerized telemetry system and was used to monitor the differential hand pressure and calculate EHB.

In the first experiment, competitive and non-competitive groups were tested for EHB using their best crawlstroke technique. The intraclass reliability coefficient of EHB was R = .915. The competitive group was found to have a significantly (p < .05) greater EHB than the non-competitive group. A stepwise discriminant analysis procedure selected EHB as the variable that best differentiated the competitive and non-competitive groups.

In the second experiment, experimental and control groups were tested. The experimental group treatment included information about using three cues to improve EHB. The intraclass reliability coefficient of EHB was R = .720. The experimental group was not found to have a significantly greater EHB than the control group. However, based on the frequency of use of the cues, the groups were using similar techniques.

In the third experiment, competitive swimmers were pre- and posttested for EHB. Between the test, their coach administered instructional cue information designed to increase EHB. The age group swimmers were found to have a significantly (p < .05) greater EHB after being coached than before. A corresponding significant (p < .05) difference in the frequency of the use of all three cues was observed.

The EHB was concluded to be a valid measure of swimming technique. The significance of the findings is that the EHB can be used to measure differences in swimming technique.

Introduction
Many swimmers with nearly perfect technique do not necessarily excel on the criterion on which they are evaluated (i.e. they do not win in their respective events). Conversely, swimmers with obvious technique flaws have set world records. A technique criterion would make it possible to separately evaluate a performance with respect to technique, allowing motor skills to be measured independently of the final performance variable (time). The objective of the study was to validate a criterion measure for swimming technique that could be immediately calculated on the pool deck in a coaching situation.

From an extension of the Hay model (Figure 1) for swimming performance (2,5), the distance of the hand movement and the contribution of the lift and drag coefficients in the direction of the desired body movement were identified as technique variables. A combination of the hand distance and lift and drag coefficients can be calculated from differential pressure measurements (the effective hand distance with respect to the water, EHW). The value of EHW was derived as: EHW = \sqrt{2(P\Delta t)} / \rho, where P is pressure, \Delta t is time, and \rho is the mass density of water. (The complete derivation of the formulas in this study can be found in reference 3.) However, such a measure is not representative of technique because the value is with respect to the water and does not vary according to the path of the hand through the water. Similar values for EHW could result from strokes with dramatic differences in the effectiveness of the technique.

By taking the body movement through the water into
account, a technique measure (the effective hand movement with respect to the body, EHB) can be calculated with respect to a fixed frame of reference (the body). The value of EHB was calculated from the formula: EHB = √3(SV*PT)² + EHW², where SV is swimming velocity and PT is pull time. Measurements of EHB on successive trials could then be compared. The effective hand movement with respect to the body (EHB) was established as the dependent variable for the present series of experiments.

The problem of the study was to determine the validity of EHB as a criterion measure for swimming technique. If EHB is a valid measure of technique, then in addition to being a reliable measure, the following conditions would be met: 1) the value of EHB for competitive swimmers is greater than for recreational swimmers, 2) the value of EHB is greater for an experimental group treated with instructional cues designed to increase EHB than for a control group exposed to a benign treatment, and 3) the value of EHB is greater after being coached with instructional cues designed to increase EHB than before being coached. The three conditions were used as the respective hypotheses for three experiments that were conducted to validate EHB.

General Procedures

Three experiments were conducted to establish the reliability and relevance of EHB as a criterion measure. Sample sizes for each experiment were determined from tables (1) with α = .05, statistical power = .80, and effect sizes predicted by referring to a meta-analysis (4). In all three experiments the subjects were first asked to complete the informed consent form. The subjects were asked to warm-up with a 100 m crawlstroke swim. Next, the subjects were given instructions for the experiment and tested for EHB on two trials of 15 m. The data were collected with the same apparatus in all three experiments.

The subjects were outfitted with the technique analysis system (TAS; U.S. Patent 4,654,010), which monitored the differential hand pressure with respect to time. The system consisted of a telemetry unit that was worn by the swimmer, a timing device, and a receiver interfaced to a computer on the pool deck.

The timing device was similar in function to that used by Maglischo and Maglischo (6). The device consisted of a 9 m cord attached to a nylon belt around the swimmer’s waist. The opposite end of the cord had clips that were 2 m apart. The clips were attached to two switches on the pool deck. As the swimmer began the trial and swam away from the timing device, the cord pulled a clip off the start switch and started the timer in the computer. After the swimmer had swum two meters, the cord pulled a clip off the stop switch and the timer was de-activated. The time for the 2 m swim allowed calculation of swimming velocity (SV).

The swimmer wore a differential pressure transducer on the hand. The transducer was mounted on a 2.5 cm by 5 cm piece of aluminum. The aluminum mount was machined so that the positive port of the transducer was exposed to the water on the palmar side of the hand and the negative port was exposed to the dorsal side. The transducer was wired to a transmitter unit that was attached to the belt worn around the swimmer’s waist.

The pressure signal was received on the pool deck and sampled by the computer every .05 sec. The same switch that started the timer in the computer was used to start the storage of pressure data. The storage of pressure data continued for 12 sec.

At the conclusion of a trial the pressure vs. time curve was displayed on the monitor. The first complete stroke cycle was selected for analysis. The initial hand exit, and successive hand entry and hand exit were identified and used to calculate the stroke time (ST), pull time (PT), and recovery time (RT). The stroke rate (SR) was calculated from the reciprocal of the ST. Stroke length (SL) was calculated as the dividend of swimming velocity and stroke rate. The pressure curve was integrated to allow calculation of EHW. The EHB was calculated from SV, PT, and EHW.

After being given instructions specific to the experiment, the subjects were asked to swim two 15 m trials. Data were collected with the TAS on both trials.

Experiment 1

Methodology

In the first experiment, competitive (n = 14) and non-competitive (n = 14) groups of college females were tested. The subjects were asked to swim two trials of crawlstroke using their best technique.

Findings

The reliability was calculated for all 28 subjects over 2 trials on the same day. The reliability coefficient
calculated for subject consistency on two trials administered on the same day was $R = .915$.

The mean career best 100 yd. (91 m) crawlstroke time of the competitive group was 54.7 sec ($SD = 2.7$ sec). The group means and standard deviations for data collected during Experiment 1 (SV, SL, SR, ST, PT, RT, and EHB) are listed in Table 1. The detected effect sizes between the competitive and non-competitive groups in EHB were 1.88 and 1.39 for trials 1 and 2, respectively.

The results of the ANOVA (7) on the primary dependent variable (EHB) are presented in Table 2. A significant group effect was detected. The group effect was tested at both levels of the trial factor. The competitive group had a significantly greater EHB than the non-competitive group for both trials ($F = 21.0$ and $F = 15.7$ for trials 1 and 2, respectively; $df = 1,52, p < .05$). There was no significant group $\times$ trial interaction or trial effect.

A discriminant analysis (7) was separately applied to the data of each trial. The dependent variables, SV, SL, SR, ST, PT, RT, and EHB, were entered into stepwise discriminant analyses. In the analyses of both trials, the EHB was the first variable selected by the computer program for inclusion. The significant values of Wilk’s lambda were $.522 (p < .05)$ and $.650 (p < .05)$ for trials 1 and 2, respectively. The classification analysis correctly predicted group membership in 86% and 79% of the cases on trials 1 and 2, respectively.

### Experiment 2

**Methodology**

For the second experiment, female, undergraduate, non-competitive swimmers were alternately assigned to experimental ($n = 16$) and control ($n = 16$) groups.

The control group treatment was benign. The experimental group was administered written instructions about using three cues to improve the technique criterion measure (EHB). The cues were: 1) to push the hand back with the palm facing the feet, 2) straighten the arm at the finish of the pull, and 3) touch the middle of the thigh with the thumb at the end of the pull. The subjects were asked to swim 100 m complying with the instructional information.

Next, the subjects were tested for two trials of crawlstroke using their best technique and complying with the instructional information. Following the testing, all subjects were administered a posttest questionnaire about their use of the three cues during the test trials.

**Findings**

The reliability was calculated for all 32 subjects over two trials on the same day. The intraclass reliability coefficient was $R = .720$.

The group means and standard deviations for data collected during Experiment 2 (SV, SL, SR, ST, PT, RT, and EHB) are listed in Table 3. The detected effect sizes between the experimental and control groups in EHB were .15 and .39 for trials 1 and 2, respectively.

The results of the ANOVA on the primary dependent variable (EHB) are presented in Table 4. There was no significant group effect. There was also no significant group $\times$ trial interaction or trial effect.

The frequency data for the posttest questionnaire were
analyzed with the Mann-Whitney U Test (8). Of the three
cues, only a significant ($U = 59.5, p < .05$) difference
between the groups was found on the frequency of use
of the third cue.

**Experiment 3**

**Methodology**
In the third experiment, 12, female, competitive swimmers (14-20 years old) were pre- and posttested with the
TAS. Between the tests, their coach administered instruc-
tional information about using cues designed to increase
EHB. Following the testing, each subject was asked to
complete a posttest questionnaire about her use of three
cues on each trial.

**Findings**
The mean career best 100 yd. (91 m) crawlstroke
time of the group was 56.3 sec ($SD = 2.1$ sec). The group
means and standard deviations for data collected during
Experiment 3 (SV, SL, SR, ST, PT, RT, and EHB) are
listed in Table 5. The detected effect size between the
trials in EHB was .60.

### Table 4
ANOVA Summary Table for Effective Distance of the Hand
with Respect to the Body (EHB) for Experiment 2

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>.172</td>
<td>1</td>
<td>.712</td>
<td>.713</td>
</tr>
<tr>
<td>Subject W/Group</td>
<td>7.230</td>
<td>30</td>
<td>.241</td>
<td></td>
</tr>
<tr>
<td>Trial</td>
<td>.087</td>
<td>1</td>
<td>.087</td>
<td>1.295</td>
</tr>
<tr>
<td>Group by Trial</td>
<td>.032</td>
<td>1</td>
<td>.032</td>
<td>.476</td>
</tr>
<tr>
<td>Trial by Subject W/Group</td>
<td>2.025</td>
<td>30</td>
<td>.068</td>
<td></td>
</tr>
</tbody>
</table>

Note: AA

### Table 5
Dependent Variable Data for Experiment 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Trial 1</th>
<th></th>
<th>Trial 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>SV (m/sec)</td>
<td>1.12</td>
<td>.11</td>
<td>1.09</td>
<td>.11</td>
</tr>
<tr>
<td>SL (m)</td>
<td>.92</td>
<td>.10</td>
<td>1.06</td>
<td>.18</td>
</tr>
<tr>
<td>SR (str/sec)</td>
<td>1.22</td>
<td>.17</td>
<td>1.05</td>
<td>.19</td>
</tr>
<tr>
<td>ST (sec)</td>
<td>1.66</td>
<td>.24</td>
<td>1.96</td>
<td>.37</td>
</tr>
<tr>
<td>PT (sec)</td>
<td>1.13</td>
<td>.19</td>
<td>1.28</td>
<td>.29</td>
</tr>
<tr>
<td>RT (sec)</td>
<td>.53</td>
<td>.23</td>
<td>.68</td>
<td>.26</td>
</tr>
<tr>
<td>EHB (m)</td>
<td>3.28</td>
<td>.56</td>
<td>3.68</td>
<td>.78</td>
</tr>
</tbody>
</table>

SV = Swimming velocity, SL = Stroke length, SR = Stroke rate,
ST = Stroke time, PT = Pull time, RT = Recovery time, EHB =
Effective hand distance with respect to the body

The results of the ANOVA on the primary dependent
variable (EHB) are presented in Table 6. A significant
($p < .05$) trial effect was detected.

The frequency data for the posttest questionnaire were

### Table 6
ANOVA Summary Table for Effective Distance of the Hand
with Respect to the Body (EHB) for Experiment 3

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>8.377</td>
<td>11</td>
<td>.762</td>
<td>5.023*</td>
</tr>
<tr>
<td>Trial</td>
<td>.980</td>
<td>1</td>
<td>.980</td>
<td>6.465*</td>
</tr>
<tr>
<td>Residual</td>
<td>1.668</td>
<td>11</td>
<td>.152</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

analyzed with the Wilcoxon Matched-Pairs Signed-Ranks
Test (8). There was a significant difference between Trial
1 and Trial 2 in the frequency of use of all three cues
($T = 0, T = 10, T = 0$, for the first, second, and third
cues, respectively; $p < .05$).

**Discussion**
The group means and standard deviations for EHB
for all three experiments are shown in Figure 2. The com-

![Figure 2. Comparison of effective hand distance with respect to the body (EHB) values for all three experiments.](image)

parisons of the group means across the three experiments
support the reproducibility of EHB values with respect
to similar groups of subjects.

The competitive swimmers of Experiment 1 were na-
tional caliber athletes and had the highest values for EHB.
The posttest (Trial 2) EHB value for the age group com-
petitive swimmers was slightly less than the value of the
university varsity competitive group of Experiment 1.
non-competitive swimmers of both Experiments 1 and 2 had very similar values for EHB. The pretest (Trial 1) EHB value for the age groupers of Experiment 3 was also similar to the non-competitive swimmers. Evidently, the age groupers were capable of exhibiting a technique similar to varsity collegiate swimmers when utilizing instructional cues. The technique of the age groupers was only as effective as recreational swimmers, when the age groupers did not utilize the cues.

The intraclass reliability coefficients of EHB were found to be between $R = .720$ and $R = .915$. The reliability coefficient for EHB for Experiment 2 was lower than on Experiment 1 and was primarily attributed to the performances of two subjects. One subject in each group produced EHB values that differed from trial 1 to trial 2 by almost 1 m. Deletion of the two most variable subjects raised the reliability coefficient of EHB to over $R = .8$.

The subjects of Experiment 2 did not all swim regularly. Therefore, they were probably not as capable of reproducing the same technique on successive trials as the subjects of Experiment 1. Also, the restriction in range of the skill level would contribute to a lower reliability coefficient than that obtained in Experiment 1.

The competitive and non-competitive groups were found to be significantly different in EHB. The significant group effect supported the hypothesis that the quantitative measure of technique (EHB) is greater for competitive swimmers than for non-competitive swimmers. The mean effect size value for Experiment 1 (1.64) was similar to the mean difference between competitive and noncompetitive groups (1.36) on different biomechanical variables as reported in a meta-analysis of swimming studies (4). The value of EHB can, therefore, be used to distinguish at least two different ability levels of swimming technique.

Additional support for the use of EHB to differentiate ability levels was provided by the discriminant analysis. The stepwise selection of dependent variables determined that EHB was more effective in differentiating the groups than any of the other measured variables.

The experimental and control groups in Experiment 2 were not found to be significantly different in EHB. Therefore, the hypothesis that the quantitative measure of technique is greater for the experimental group treated with learning in cues than for the control group exposed to a benign treatment, was not supported. Since the results of the posttest questionnaire indicate that the groups differed in the frequency of use of only one cue, they were evidently using similar techniques. If the groups were using similar techniques, then only a small between-groups difference in EHB would be expected. No significant difference in EHB for two groups performing a similar technique could serve as support for EHB as a valid measure of technique.

The significant difference between the pre- and posttest value of EHB in Experiment 3 supported the hypothesis that the quantitative measure of technique is greater after being coached with instructional cues than before being treated. The effect size for EHB (.60) was similar to the mean value (.73) for biomechanical variables in within-group studies reported in a meta-analysis (4). A corresponding significant difference between the pretest and the posttest in the frequency of use of all three cues was observed. The value of EHB can, therefore, be used to determine an improvement in swimming technique.

Conclusions
The reliability of EHB was supported in Experiments 1 and 2. The validity of EHB was supported in Experiment 1, as an obvious difference in technique (between competitive and recreational swimmers) resulted in a significant difference in EHB. The validity of EHB was supported in Experiment 2 in the sense that a minor difference in technique resulted in a nonsignificant difference in EHB. The validity of EHB was supported in Experiment 3, as a significant difference in all the surveyed technique cues resulted in a significant difference in EHB. It was concluded that EHB is a valid measure of swimming technique.

The results of the experiments can be compared with respect to the number of cues that had significant differences in the frequency of use and the magnitude of the treatment effect. In Experiment 2, only one cue had a significant difference between groups in frequency of use. The mean magnitude of the treatment effect of Experiment 2 was .27. In Experiment 3, all three cues had significant differences in the frequency of use between the pretest and the posttest. The magnitude of the treatment effect of Experiment 3 was .60. From the results of Experiments 2 and 3 it seems possible that the number of cues that are used by the subjects might have an additive effect on the value of EHB.

The value of coaching as opposed to a nonpersonal treatment could be attributed to the difference in the results of Experiments 2 and 3. The written treatment in Experiment 2 was only effective in eliciting a significant difference in the frequency of the use of one cue and a nonsignificant difference in EHB. The coaching in Experiment 3 elicited a significant difference in the frequency of use of all three cues and a significant difference in EHB. The experimental results support the value of coaching to increase the EHB of swimmers.

The TAS is a convenient and efficient method to collect time and pressure data on hand movements during swimming and to provide a swimmer with quantitative data immediately after a performance. The TAS can be used in teaching, coaching, and research situations to provide quantitative feedback about EHB before and after
the administration of instructional material. The TAS can also be used to provide information about several other variables related to swimming performance, such as swimming velocity, stroke length, stroke rate, and other component pressure and time variables. The testing can be repeated on a periodic basis throughout a practice session/season/year/career.

References

Functional Maximal Aerobic Power and Prediction of Swimming Performances

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Abstract

The functional and maximal aerobic power (FMAP) of 292 swimmers (males and swimmers) of different ages (11-12, 13-14, 15 years) were evaluated according to a maximal multistage swim test recently developed (2). In addition, an estimate of the energy cost of swimmers, the arm stroke index (ASI), i.e. the ratio of the number of arm strokes and swimming velocity, was measured. The results indicate a clear progression of both of these variables (FMAP and ASI) throughout the ages. Using the best performance times realized by these swimmers, two regression equations for the prediction of performance times were established, taking into account the following variables: FMAP, ASI, age, sex, and the swimming distance. For the 200, 400, and 800 m, the equation is: \( Y = 0.98 + (0.039 \times \text{stage}) - (0.74 \times 10^{-3} \times \text{distance}) \), with a correlation coefficient of 0.955 and a standard error of estimate of 3.26%. Another regression equation was established to predict performances for the 50 and 100 m swims. These data can be used as a tool to gain information on the swimming economy and aerobic capacity of a swimmer.

Introduction

Direct evaluation of maximal aerobic power (\( \dot{V}O_2 \text{max} \)) in swimming has been done using different testing procedures (for a review, see Lavoie and Montpetit (4)). In recent years, however, field tests based on the measurement of functional maximal aerobic power (FMAP) were introduced (5,6). The FMAP is a combined index of maximal aerobic power and mechanical efficiency. In other words, the FMAP corresponds to the velocity (running or swimming) at which \( \dot{V}O_2 \text{max} \) is reached. This maximal aerobic velocity can then be used to predict \( \dot{V}O_2 \text{max} \), but more importantly, it can be used to prescribe a specific training programme.

The notion of functional maximal aerobic power has been recently applied to swimming with the construction of a field test in which the swimming velocity was increased by 0.05 m-s\(^{-1}\) every 2 min, beginning at a velocity of 1.0 m-s\(^{-1}\) (2,3). This test, which permits the determination of the maximal aerobic swimming velocity, was used in connection with the measurement of an estimate of swimming economy: the arm stroke index (ASI). This index of swimming economy was based on a study presented by Craig and Pendergast (1), and consists simply of the number of arm strokes for a given distance (125 m, free style) divided by the swimming velocity in m-s\(^{-1}\).

The purpose of the present investigation was twofold. First, the FMAP and ASI (free style) was measured in a large number of competitive swimmers in order to establish norms for these two parameters taking into account the age and the sex of the swimmers. Second, the possibility of predicting performances from the FMAP and ASI values was explored.

Methods

A large group of active competitive swimmers (n = 292) from several swimming teams around Montréal volunteered to take part in this study. These swimmers from both sexes were classified in three groups according to their age: 11-12 (52 males, 65 females), 13-14 (41 males, 61 females), and 15+ years (34 males, 39 females). These swimmers had their FMAP and ASI evaluated in approximately the middle of the training season.
The FMAP was evaluated through a maximal multistage swim test recently developed by Lavoie et al. (2). Briefly, this test consists of swimming a series of continuous 2-min stages at a progressively increasing velocity until the swimmer is unable to keep up with the speed. The last stage reached corresponds to the maximal aerobic velocity and is termed the FMAP. The ASI was also measured during the test. The number of arm strokes (averaged for 125 m) was divided by the swimming velocity in m·s⁻¹ (2). The ASI was calculated during different stages of the multistage swim test, and the best score among the stages for each swimmer was retained.

During the course of these evaluations the best performances (50, 100, 200, 400, and 800 m) registered by these swimmers during the most recent swimming meet were recorded. To predict swimming performance, these performance times were considered as the dependent variable and were multiple regressed with FMAP, ASI, swimming distance, sex, and age. Sex and age group comparisons for FMAP and ASI were made using unpaired Student t-tests.

Results

Averaged values for FMAP and ASI according to sex and age groups are presented in Fig. 1 and 2. Fig. 1 shows an expected increase in FMAP with age for both sexes (P < 0.01). The increase in FMAP between 11-12 and 13-14 year groups corresponded on the average to 13% in female as compared to 40% in male swimmers. This led to significant differences (P < 0.02) between male and female swimmers in 13-14 and 15+ year groups. However, such a difference was not observed in the 11-12 year group. A significant (P < 0.01) decrease in ASI with age in both sexes was also observed (Fig. 2). A significant (P < 0.02) difference between sexes was observed in the 15+ year group but not for the 11-12 and 13-14 years old swimmers.

Two regression equations for the prediction of performance times were established, using FMAP (stage), ASI, age, sex, and the swimming distance. For the 200, 400, and 800 m swims, the equation is: \( y = 0.98 + (0.039 \text{ stage}) - (0.74 \times 10^{-3} \text{ ASI}) + (0.0016 \text{ age}) - (0.0037 \text{ sex}) - (0.18 \times 10^{-2} \text{ distance}) \), with a correlation coefficient of 0.955 and a standard error of estimate of 3.26% (n = 200). For the 50 and 100 m swims, the equation is: \( y = 1.576 + (0.033 \text{ stage}) - (0.0014 \text{ ASI}) + (4.88 \times 10^{-3} \text{ age}) - 0.0459 \text{ sex}) - (0.0322 \text{ distance}) \), with a correlation coefficient of 0.925 and a standard error of estimate of 5.21% (n = 269). The age group in the equations corresponds to the number 11, 13, or 15, and the sex to the number 1 and 2 for males and females respectively. The predicted variable "y" is velocity in m·s⁻¹.

Table 1 shows an example of such predictions for the 200 m free-style event.

Discussion

The results of the present investigation demonstrate that FAMP and ASI are good predictors of swimming performances over a large range of swimming events. A close look at Table 1 reveals that, in fact, FMAP is the most important factor in the prediction. Keeping all other
not observed to the same extent in the two other age groups. Finally, it is important to underline that the ASI is an estimate of swimming economy which is not solely related to technical ability, but also to other parameters such as morphology, body position, and strength.

Conclusions

In summary, the results of the present study show that the FMAP and the ASI can be used as predictors of swimming performances for different swimming events. The two prediction equations proposed can be used to determine a target time that a swimmer should be able to realize according to his or her FMAP and ASI results. The equations can also be used in the reverse way; that is to determine how much a swimmer must improve his or her FMAP and/or ASI to realize a given performance. The two ways can lead to a more realistic approach of what a swimmer can do based on his or her aerobic capacity and mechanical efficiency. In addition, Fig. 1 and 2 can be used to classify the aerobic potential and swimming economy of a subject among a large group of swimmers of the same age and sex. It is therefore possible for a coach to get a practical unbiased evaluation of aerobic capacity and swimming economy and to make corrections accordingly. Finally, by comparing the predicted time to the real time realized in competition, it is possible to get some information on the anaerobic potential of a swimmer. Since the predicted time is mainly determined from an aerobic predictor (FMAP), a better than predicted performance must reflect the involvement of the anaerobic component.

Acknowledgements

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References

THE JOURNAL OF SWIMMING RESEARCH

— AUTHOR GUIDELINES —

(Revised February, 1987)

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2. ABSTRACT. The abstract (200 words or less) should summarize the study's purpose, methodology, results, and conclusions. It should include a summary statement that provides some interpretation of the findings and their implications to the on-deck coaching and training of swimmers.

3. TEXT—The text should contain separate sections for the:
   a. Introduction. This section should state the purpose, the rationale, and the essential related literature.
   b. Methodology. This section should include a clear description of the experimental subjects and their controls. The description of the methodology should provide enough detail for others to duplicate the study. References should be provided for established methods and statistical procedures should be supported with rationale.
   c. Findings. The findings presented in the text, tables, and figures should follow a logical and parallel sequence. The statistical significance of appropriate results should be acknowledged.
   d. Discussion. This section should emphasize the study's important and original aspects while avoiding a repeat of data presented in the findings section.
   e. Conclusion. The author should provide conclusions supported by their data. This section of the manuscript is of particular importance to the purpose of the journal. It should be of at least 500 words in length and provide in simple, laymen terms, an interpretation of findings and implications to the on-deck coaching and training of swimmers.

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