THE JOURNAL OF
SWIMMING RESEARCH

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THE JOURNAL OF SWIMMING RESEARCH is an official publication of the American Swimming Coaches Association in cooperation with the United States Swimming's Sports Medicine Committee. The American Swimming Coaches Association (ASCA) is an educational and professional service organization for swimming coaches. Its national office is located at 304 SE 20th Street, Fort Lauderdale FL 33316, United States Swimming (USS) is the National Governing Body for competitive swimming in the United States. It is a Group A member of the United States Olympic Committee. Its national headquarters is located at 1750 East Boulder Street, Colorado Springs, CO 80909.

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THE JOURNAL OF SWIMMING RESEARCH entitles the subscriber to 1 issue by the American Swimming Coaches Association from 304 SE 20th Street, Fort Lauderdale FL 33316. Telephone (305) 462-6207. Subscription rates are $35.00 (Canada & Mexico), and $35.00 (USA). The journal is printed by the Western Newspaper Publishing Co., Inc. of Indianapolis, IN.

Acceptance of advertising material does not imply endorsement by the American Swimming Coaches Association or United States Swimming. Author's opinions expressed in the articles are not necessarily those of the staff and/or Boards of the American Swimming Coaches Association or United States Swimming.

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Editor's Preview

The application of sciences to competitive swimming takes many forms and may include areas such as physiology, biomechanics, psychology, nutrition, biochemistry, medicine, and strength. About the only branch of science we have not applied to understanding swimming is astronomy. Indeed, the papers in this issue represent the broad range of science in swimming with papers concerning energetics of dry land training (Sexsmith, et al), how well heart rate reflects lactate or anaerobic threshold (Harrison, et al), physiological adaptations of novice swimmers (Rinehardt, et al), a new device for measuring water resistance on swimmers (Sheehan, et al), and a strategy for keeping track of swimmers' nutrition (Carey).

In the paper by Sexsmith, et al a study is described in which the energetics of performing dry land surgical tubing exercise were compared with those resulting from a similar exercise session on a Biokinetic swim bench. The results suggest that both dry land modes produce elevations in metabolic rate and blood lactate concentrations but that these responses were greater during swim bench exercise. Curiously, although blood lactate concentration was substantially increased while working on both devices, oxygen uptake was relatively low (26% of VO₂max on the bench, and 21% of VO₂max with tubing). Thus, because of the small muscle mass involved in these activities, a physiologic stimulus great enough to result in improved whole-body aerobic capacity may not be reached. However, there may be enough localized stimulus in the upper body to at least maintain adaptations of these muscles during periods of forced detraining. This at least provides us with rationale to examine the efficacy of these modes in preventing or minimizing the detraining response. Whether coaches could expect these dry land modes to augment the aerobic adaptations gained in the water training seems doubtful unless the intensity of the repetitions can be substantially increased, especially for the surgical tubing.

The second paper in this issue (Harrison, et al) describes a study that compared two previously developed tests of individual anaerobic threshold (IAFRT): one based on heart rate measurements, and one using blood lactate determinations. Those who had proposed the heart rate method claimed that this method could be used reliably to estimate IAFRT by those who cannot measure blood lactate concentrations. The results demonstrated that the velocities obtained with the non-invasive protocol did not correlate with the velocities from the invasive and reference protocol. The authors propose that this may, in part, be due to short 50 meter swims used in the non-invasive method which may not allow enough time for the swimmers' true heart rate response to each velocity to be reached. A further study of this type but using longer repeats such as 200-400 meters should help settle this issue of whether there is a suitable heart rate method for estimating swimmers' IAFRT.

The paper by Rinehardt, et al examines the very basic question of whether novice, summer league swimmers in various age groups can expect to experience physiological adaptations to training despite the fact that much of their training involves drills and technique instruction. Over a six week season these swimmers increased muscular strength and power while oxygen uptake and blood lactate concentration decreased during a submaximal effort. In addition, performance times also decreased. Aerobic power increased only in the 11-12 and 13-17 age groups. The physiological benefit of technique instruction seems therefore to be in allowing the swimmers to decrease the effort required to swim a given submaximal speed; i.e., an improved economy rather than an increase in aerobic power. The authors discuss the ramifications of these findings with respect to developing swimmers throughout their competitive careers.

Carey's paper describes a nutrition guidebook designed specifically for busy swimmers and evaluates the effectiveness of this approach. Because swimming training places such large demands on the athletes' fuel reserves and nutritional balance, and because performance is so closely dependent on nutritional status, practical tools for monitoring diet are timely and relevant.

The final paper in this issue is a technical note by Sheehan, et al describing a new device for measuring frictional, form, and wave drag created on swimmers' bodies as they are towed through or under water. The intent of this paper is to share the design with others who may wish to engage in future studies of drag in swimmers. Potential applications of this device include specific analysis of various drag forces with different stroking patterns, body positions, and even after shaving.

As I said in the beginning of this piece, these papers span a wide range of science applied to swimming. Each one of the papers contributes, in some way, to our knowledge of competitive swimming yet each implies an almost limitless amount of future research that needs to be explored. Let us hope that these authors and others will continue to help lead us in our search for knowledge and that along the way, coaches will use this knowledge to further improve the development of competitive swimmers.

Rick Sharp
Acute Responses to Surgical Tubing and Biokinetic Swim Bench Interval Exercise

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Abstract
To quantify and compare the acute physiological responses to a submaximal interval training protocol, 22 elite male competitive swimmers (18.3 ± 0.6 yr; 69.2 ± 1.8 kg; 174.7 ± 1.3 cm; VO₂max 53.9 ± 1.1 ml·min⁻¹) performed three sets of five, 60 s repeats at 38 strokes per minute interspersed with 30 s rest intervals using surgical tubing (ST) and Biokinetic swim bench (SB) (2.05 m·s⁻¹). A five minute recovery was provided between sets. Heart rate (HR), minute ventilation (Vė) and oxygen consumption (VO₂) were measured for the final 30 s of each set. Venous lactate (HLa) was assessed at rest and four minutes post-final repeat. The ST modality elicited lower responses (p ≤ 0.01) for HR, Vė and VO₂ at all measurement times. For both modes, only HR increased significantly over each set. Post-exercise HLa was significantly elevated, but again ST elicited the lower response. These responses appear attributable to the large recruitment of motor units characteristic of upper body exercise, a possible occlusion effect exceeding vascular perfusion pressure, and thermoregulation. The differential responses observed between exercise modes may be due to dissimilar force generation requirements and hence, different motor unit recruitment patterns. Results suggest that both ST and SB protocols could provide effective, albeit different, training overloads.

Key Words: swimmers; surgical tubing; Biokinetic swim bench; dryland training; cardiorespiratory; lactate

Introduction
Competitive swimming is a sport which utilizes specific, submaximal interval dryland training methodologies to concurrently provide resistive and metabolic overloads (15). Two commonly used modalities involve submaximal, interval based swimming specific exercise utilizing the Biokinetic swim bench (SB) or surgical tubing (ST). The SB is a modality which approximates an isokinetic device across its ten velocity settings, and although the instrument substantially reduces hand and arm acceleration once the set velocity is reached, there is still a uniform acceleration proportional to the force applied by the musculature throughout the range of motion (21). Alternatively, surgical tubing can be characterized as a variable resistance training mode where the development of tension is dependent upon the gauge of tubing utilized, the initial length of the tubing, the amount of stretch placed on it, and the range of motion performed. Previous research involving the Biokinetic swim bench has focused upon quantification of maximal cardiorespiratory and metabolic responses (1,4,16) or the identification of relationships between power (as calculated by the work integrator of the swim bench) and swimming performance (7,22). Only one investigation has described the acute metabolic as well as cardiorespiratory responses to submaximal interval exercise using this mode (18).

The cardiorespiratory and metabolic responses to submaximal, dryland exercise utilizing surgical tubing have not been quantified. Corry and Powers (6) described cardiorespiratory responses to swimming specific, alternate arm elastic shock cord exercise with subjects in a standing, bent-over position during a discontinuous, high cadence protocol designed to elicit maximal values for oxygen consumption. Although the authors provided a load-elongation curve, they did not elaborate on the type or size of cord used.

An investigation which quantifies the acute cardiorespiratory and metabolic responses to submaximal, swimming specific interval exercise utilizing surgical tubing, and compares those responses to an identical Biokinetic swim bench protocol, would provide preliminary information towards understanding the
nature of this training stimulus. This information would enhance the ability of coaches to maximize the efficacy of dryland resistance training programs utilizing these modalities. Therefore, the purpose of this study was to quantify and compare selected acute metabolic and cardiorespiratory responses to an interval exercise protocol utilizing surgical tubing and Biokinetic swim bench dryland training modes.

Methods
Twenty-two subjects were chosen from the entire volunteer population (N = 63) of male competitive swimmers who had swim performance times within six months prior to the study which would have placed them on the New Brunswick Canada Games swimming training team. Subjects were between 14 and 24 years of age, in their off-season, and had sustained no injury (i.e., causing them to miss two or more weeks of training) to the musculature or joints of the arms, shoulders or legs within three months prior to the study. After standardized familiarization with all of the tests and procedures involved in the investigation, each subject provided informed consent. Descriptive data were obtained during the familiarization session including percentage body fat which was assessed from skinfold thickness according to the Durnin and Rahaman (9) protocol. Prior to each testing session, subjects abstained from intense physical activity for 48 hours, refrained from ingesting food or beverages for two hours, and wore similar clothing for each test which occurred at approximately the same time of day. Subjects participated in three testing sessions with the initial one consisting of a running treadmill test to volitional exhaustion utilizing the Canadian Association of Sports Sciences recommended protocol (14) to determine peak values for heart rate (HR), minute ventilation ($V_e$) (BTPS), oxygen consumption ($\dot{VO}_2$) (STPD) and venous lactate (HLa).

The next two sessions (ST and SB) involved the performance of an interval exercise protocol which consisted of three sets of five 60 s exercise bouts, with subjects being given 30 s rest after every bout and a five minutes break upon completion of each set. To minimize potential confounding effects, two to fourteen days elapsed between the graded treadmill test and the first interval testing session, and there was a two to seven day gap between performances of the ST and SB protocols. A randomized, counterbalanced design determined the order in which the subjects performed the surgical tubing and swim bench sessions. Data collection procedures for the interval protocol are described in Table 1. During the interval performances, subjects mimicked the propulsion portion of a butterfly or double arm freestyle pull. The recovery action consisted of a reversal of the propulsion movement pattern without the sculling motions. Participants began each repeat with their arms in position to start the propulsive phase of the stroke. The stroke rate of 38 strokes per minute ($S\cdot min^{-1}$) was indicated by a metronome with each beat prompting the subject to alternately initiate the recovery or propulsion phase. This rate was selected to ensure the provision of a resistance overload, similar to what might be observed during in-water resistance training utilizing paddles or tethered swimming. For both interval exercise conditions the athlete’s prone, chin at the edge of the bench, position was maintained with a velcro strap placed under the bench and securely wrapped around the swimmer’s waist. Leather mittens affixed to the paddles prevented slippage of the participant’s hands. The mittens were removed during the five minute recovery periods while swimmers rested in a prone position on the bench.

Calibration of the Biokinetic swim bench, which was set to velocity three, was verified according to the procedure of Sharp et al. (22). Work (kpm) was recorded directly from the work integrator on the SB at the completion of each 60 s bout and expressed as average power (watts).

For the ST session, the bench portion of the Biokinetic swim bench was detached and centered to a pulley apparatus. A bracket, centrally located between the pulley system, secured the single piece of tubing to a wall such that proportional lengths of 180 cm to each arm were maintained. The initial length of the tubing was standardized for all subjects by ensuring that it was completely straight but not stretched when the athletes were on the bench with their arms positioned to begin the propulsion phase of the stroke. The surgical tubing used during the study was 7.9 mm bore by 2.4 mm wall thickness latex tubing (Fisher catalog #14-178-5e). Load-elongation analysis was performed on all used pieces as well as on new, unused tubing with no differences in percent elongation or linearity being observed over the range of motion utilized by subjects.

All respiratory measurements were obtained using an on-line, Apple IIe based exercise metabolic test system consisting of a P.K. Morgan ventilometer, an Ametek Applied Electrochemistry S-3A oxygen analyzer, and a Beckman LB-2 carbon dioxide analyzer coupled with
S&M Instrument software. Ventilation volumes were verified utilizing a 120 litre Collins chain-compensated gasometer. Heart rates were determined from a Cardio- rater CR51 electrocardiograph coupled with a Cambridge VS4 stripchart recorder. Subjects were prepared with three, 3M Red Dot electrodes placed at the left (V6), right (V6 plus 2 to 5 cm laterally in a transverse plane) and terminal cervical vertebrae (ground) positions. This placement prevented subjects from lying directly on the electrodes thus reducing potential interference with cardiac signal collection. All data acquisition systems were calibrated prior to a testing session with the calibration verified after each test. For the purposes of this study, during the interval protocol performances, $\dot{V}_{O_2}$, $\dot{V}_e$ and HR were assessed over the final 30 seconds of the last repeat of each exercise set.

Lactate concentration was assessed from antecubital venous blood samples obtained at each session. Collection occurred prior to the standardized warm-up procedures and either five minutes following completion of the maximal treadmill test or four minutes after the ST and SB interval exercise sessions. All samples were drawn with subjects in a seated position. After preparation and centrifugation, the resulting supernatant was frozen and analyzed within 90 days (3) for lactate concentration (Sigma Chemicals kit 826-UV).

All results were expressed on an absolute basis as well as relative to the peak values obtained from the maximal treadmill test. A one-way analysis of variance for repeated measures was utilized to compare total power output across the SB exercise sets. To allow comparisons between the two specific exercise modes as well as between the three exercise sets, a three-way analysis of variance for repeated measures was conducted on the absolute values for each of the cardiorespiratory and metabolic variables. Test order (ST or SB protocol) was included in the statistical model as a classification variable. When appropriate, an orthogonal contrast post-hoc procedure was performed. In all cases, an alpha of $p \leq 0.01$ was required for the acceptance of a significant difference between means.

### Results

The descriptive characteristics of the subjects (Table 2) were similar to those obtained in previous studies involving age group and/or university, male elite provincial swimmers (5,13). During the SB interval protocol, though not statistically significant, total power output decreased progressively across the three sets (Table 3).

<table>
<thead>
<tr>
<th>SET</th>
<th>REPEAT</th>
<th>POWER (watts)</th>
<th>POWER$^1$ (watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>64.9 ± 3.9</td>
<td>299.0 ± 14.5</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>60.6 ± 3.6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>57.8 ± 2.9</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>57.6 ± 2.7</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>58.0 ± 3.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>62.5 ± 3.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>57.4 ± 3.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>56.6 ± 2.8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>57.0 ± 3.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>57.4 ± 3.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>55.4 ± 3.1</td>
<td>290.9 ± 14.6</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>54.5 ± 3.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>54.2 ± 2.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>54.2 ± 2.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>60.1 ± 3.5</td>
<td>278.4 ± 13.9</td>
</tr>
</tbody>
</table>

$^1$POWER$^1$ = Total Power Output Per Set

Comparison between the two modes revealed that the HR, $\dot{V}_e$ and $\dot{V}_{O_2}$ responses to the ST protocol were significantly lower for all exercise sets (Table 4). For both the ST and SB protocols, HR increased significantly over each subsequent set, $\dot{V}_e$ was significantly higher for set three compared to set one, and no significant difference existed across sets for $\dot{V}_{O_2}$ (Table 4). Venous lactate

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>SET</th>
<th>SB</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (beats•min$^{-1}$)</td>
<td>1</td>
<td>165.1 ± 4.3</td>
<td>140.2 ± 3.9$^a$</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>172.2 ± 4.0$^b$</td>
<td>148.6 ± 4.2$^a$</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>180.7 ± 4.0$^{ab}$</td>
<td>156.2 ± 4.5$^{ab}$</td>
</tr>
<tr>
<td>$\dot{V}_e$ (l•min$^{-1}$)</td>
<td>1</td>
<td>70.3 ± 4.0</td>
<td>47.1 ± 1.9$^a$</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>72.8 ± 1.9</td>
<td>50.7 ± 1.9$^a$</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>76.2 ± 3.8$^b$</td>
<td>59.8 ± 2.0$^a$</td>
</tr>
<tr>
<td>$\dot{V}_{O_2}$ (ml•min$^{-1}$•kg$^{-1}$)</td>
<td>1</td>
<td>25.9 ± 0.7</td>
<td>20.6 ± 0.6$^a$</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>26.8 ± 1.1</td>
<td>20.9 ± 0.9$^a$</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>26.8 ± 1.0$^b$</td>
<td>22.0 ± 0.9$^a$</td>
</tr>
<tr>
<td>HLa</td>
<td>Pre</td>
<td>1.1 ± 0.0</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>7.6 ± 0.5$^a$</td>
<td>4.0 ± 0.2$^a$</td>
</tr>
</tbody>
</table>

$^a$ Significantly Different from SB ($p \leq 0.01$)

$^b$ Significantly Different From Set 1 or Pre ($p \leq 0.01$)

$^c$ Significantly Different From Set 2 ($p \leq 0.01$)
values were elevated significantly after completion of both exercise protocols (Table 4) with the ST elicited response being significantly lower. For all analyses, no significant differences were attributable to the order in which subjects performed the ST and SB test sessions. Table 5 contains the cardiorespiratory and metabolic responses to the ST and SB exercise protocols expressed relative to the peak values derived from the maximal treadmill test.

Table 5
Cardiorespiratory and Metabolic Responses to Surgical Tubing (ST) and Biokinetic Swim Bench (SB) Interval Exercise Protocols Expressed as a Percentage of the Peak Values Derived from the Maximal Treadmill Test (x ± SEM; N = 22)

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>SET</th>
<th>SB</th>
<th>ST</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (%)</td>
<td>1</td>
<td>77.1 ± 1.8</td>
<td>65.4 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>80.4 ± 1.8</td>
<td>69.4 ± 1.7</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>84.4 ± 1.7</td>
<td>72.9 ± 1.9</td>
</tr>
<tr>
<td>V̇E (%)</td>
<td>1</td>
<td>48.0 ± 1.7</td>
<td>32.4 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>49.6 ± 2.2</td>
<td>35.0 ± 1.8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>51.6 ± 3.5</td>
<td>34.9 ± 1.7</td>
</tr>
<tr>
<td>V̇O₂ (%)</td>
<td>1</td>
<td>46.7 ± 1.4</td>
<td>35.9 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48.1 ± 1.0</td>
<td>37.5 ± 1.6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>48.1 ± 1.8</td>
<td>39.6 ± 1.6</td>
</tr>
<tr>
<td>HLa (%)</td>
<td>Post</td>
<td>76.2 ± 5.6</td>
<td>42.0 ± 3.3</td>
</tr>
</tbody>
</table>

Discussion

A previously unavailable, quantified description was provided for the surgical tubing elicited cardiorespiratory and metabolic responses to a submaximal, multiple set interval exercise protocol.

Power output, V̇O₂ and V̇E remained relatively constant during the three exercise sets implying that the exercise intensity did not change appreciably over the course of either the ST or SB procedures. Heart rate was the only response to increase significantly across all three sets during both modes. The relative stability of these measures coupled with the significant increase in heart rate as well as the duration of the protocol, suggest that blood pressure and thermoregulatory factors such as an increased skin blood flow and sweating rate probably contributed to evoking the observed increase in heart rate. Elevations in peripheral blood flow and sweating rate associated with thermoregulatory processes would decrease the central blood volume as well as the venous return and stroke volume, hence, heart rate would be increased to maintain the relatively constant cardiac output demanded by the exercise (10,20). Furthermore, the duration of the protocol, coupled with the progressive decrease noted in total work during the SB test, suggest the occurrence of alterations in motor unit recruitment. Fatigue of motor units with subsequent recruitment of less efficient force producing ones may have precipitated a slight increase in the cardiac output requirements and peripheral resistance thus contributing to the progressive rise in the heart rate.

Results indicated that both swimming specific dryland resistance training modes stressed the anaerobic lactic energy production pathway given the elevated lactate response and the relatively low oxygen consumption values obtained. Generally, blood lactate concentrations exceeding 4 mmol·L⁻¹ are considered to be indicative of a substantial contribution from anaerobic sources (11). The higher lactate level attained following the SB procedure (7.6 mmol·L⁻¹), coupled with the similar oxygen consumption values noted across both interval conditions, suggests that more power was generated during the SB performance. The resistance design characteristics of the Biokinetic swim bench combined with the elevated force generation requirement necessary for initiation of the propulsive phase of the double arm pull when using this modality (17,21) probably account for the higher lactate values.

The general responses observed during both the ST and SB interval protocols appear attributable to the large recruitment of motor units characteristic of upper body exercise suggesting a possible occlusion effect exceeding vascular perfusion pressure (20). During upper body exercise the relatively small muscle mass utilized places a large burden upon the body’s metabolic systems primarily through the increased peripheral resistance offered which decreases vascular perfusion rates and reduces both venous return and the muscle’s oxygen extraction capabilities (19,23). Consequently oxygen consumption and cardiac output demands of the exercise are met through increases in myocardial contractility. Moreover, when blood flow through a working muscle is compromised, a greater dependence is placed upon energy production via anaerobic glycolysis which is reflected by an elevation in venous lactate concentration and minute ventilation (2,8). As the exercise continues and fatigue ensues, both the pattern and number of motor units recruited are adjusted to maintain the force generation requirements.

A factor which influenced the general physiological response obtained was the prone body position utilized during the interval protocols. Compared to exercise performed in a weight-bearing posture, it has been demonstrated that metabolic and cardiorespiratory responses are attenuated when exercising in a supine position through a reduction in the active muscle mass as well as an enhancement of venous return (23,24). This is supported by the work of Corry and Powers (6) who noted high values (HR 96.2%, V̇O₂ 78.5%, V̇E 83.8%) relative to a maximal treadmill test, in their elastic shock cord study protocol performed in a standing, bent-over position.
The differential physiologic responses observed between exercise modes may be due to their dissimilar force generation requirements and hence, the unique motor unit recruitment and synchronization patterns characteristic of each exercise modality. Obrecht and Clarys (17) demonstrated that a large recruitment of motor units occurs at the commencement of the pull on the SB. Surgical tubing, given its elastic nature, should elicit a relatively smaller motor unit recruitment at the beginning of the stroke which would continue to increase throughout the range of motion. Furthermore, the recovery action on the ST requires the subject to resist the tendency of the tubing to ‘snap’ back, causing the musculature to contract eccentrically, possibly reducing the energy cost (12) during this portion of the movement pattern. The SB mode potentially induces a greater isometric contraction of the legs and back against the restraining belt for stabilization purposes which, coupled with the concentric contraction required to assist with the rope retraction, would contribute further to the total exercising muscle mass and metabolic cost. Hence, the higher HR, \( \bar{VO}_2 \), \( V_e \) and HLA values obtained during the SB session presumably resulted from a greater metabolic demand and an increased peripheral resistance.

In summary, for the interval exercise protocol assessed, both the surgical tubing and Biokinetic swim bench modes elicited physiologically significant responses. Exercise performed on the Biokinetic swim bench resulted in significantly higher responses at all measurement times for all indices. However, these responses could be easily altered by modifying the exercise intensity through changing the SB dial setting, gauge/length of surgical tubing or stroke rate.

Applications

The results of this study suggest that submaximal, surgical tubing and Biokinetic swim bench interval exercise protocols can provide effective, albeit different, training overload. When expressed on a relative basis, given the comparatively small musculature involved, the substantial responses observed for the physiological variables suggest that both modalities could be used effectively for specific interval exercise prescriptions to provide a metabolic dryland training stress to swimmers. Given that peripheral metabolic adaptations are lost rapidly during periods when athletes are unable to swim, appropriately designed dryland SB or ST training could be utilized to maintain adaptations in the upper body musculature. Though further research is necessary to substantiate these suggestions, the anaerobic lactic energy system could be stressed by doing the following: increasing the size of tubing, shortening existing tubing, decreasing the velocity setting of the swim bench, or increasing the stroke rate. The capacity of the lactate system could be stressed by modifying the exercise set prescription.

Swimmers could perform four or five sets consisting of one and a half minutes at a very high intensity on the swim bench or surgical tubing interspersed with approximately three or four minutes of active recovery. Similarly, the rate of lactate production could be taxed by doing four or more sets of thirty second bursts of arm exercise coupled with one or two minutes of active recovery. In contrast, peripheral aerobic detraining could be minimized by having swimmers perform ‘in-water’ aerobic sets using a light weight of tubing or alternatively, a high velocity setting on the swim bench.

Acknowledgements

This study was supported, in part, by grants from the University of New Brunswick (Grant 17-71) and Swim Ontario.

The authors gratefully acknowledge the assistance of Drs. Peter Cashion and Bill Seabrook from the Faculty of Science for providing access to equipment necessary to undertake this study.

References

Non-Invasive and Invasive Determinations of the Individual Anaerobic Threshold in Competitive Swimmers

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The University of Western Australia

Abstract

Five male and seven female competitive swimmers randomly performed on different days a non-invasive test (heart rate measurement, [modified from Cellini et al. (2)]) and an invasive test (blood lactate measurement) [modified from Stegmann et al. (15)], for the determination of the individual anaerobic threshold (IAnt).

Based on (2), a series of graded, slow to fast, 10-15 x 50m freestyle swims was used, with a 10s pause between each 50m effort to measure heart rate (HR) and record swimming time. To correspond to the three minute workloads recommended for use by (15), a series of graded, slow to fast, 4-5 x 300m freestyle swims was used. During each 300m effort, the time swam for each 50m split was recorded. Immediately upon completion of each 300m swim, HR was measured and capillary blood (earlobe) collected for the determination of blood lactate concentration [HLa], during a one minute recovery interval. Blood was also collected for measurement of [HLa] 2, 5 and 10 minutes after the final 300m swim.

The determination of the non-invasive IAnT involved plotting time swum (velocity) for each 50m effort against HR measured, whereas the invasive IAnT required time swum (velocity) for each 300m effort to be plotted against both HR and [HLa].

A non-significant correlation ($r = -0.09$) was found between the non-invasive IAnT HR and the invasive IAnT HR. The ($\bar{x} \pm S.E.$) HR for the invasive IAnT was higher (187 ± 11 b.min$^{-1}$) than for the non-invasive IAnT (172 ± 10 b.min$^{-1}$). Despite the higher HR value, the swim velocity recorded at the invasive IAnT (2.29 ± 0.47 m.s$^{-1}$) was slower than the velocity recorded at the non-invasive IAnT (2.38 ± 0.62 m.s$^{-1}$). The correlation between these velocities was also non-significant ($r = 0.435$). It was concluded that determining the IAnT non-invasively (by using HR) did not correspond to the same IAnT established invasively (by using [HLa]).

Introduction

An elite swimmer dedicates many hours per week to training and it is important that maximum benefits are derived from this commitment. A major focus of training is to improve the maximum power and capacity of the energy system(s) required for a particular event.

The three systems which provide energy for muscular contraction are the muscular stores of adenosine triphosphate (ATP) and phosphocreatine (PC), glycolysis and oxidative metabolism. Sprints utilize predominantly ATP-PC stores and anaerobic glycolysis, whereas middle distance and distance swimmers use predominantly oxidative metabolism (12).

The establishment of the individual anaerobic threshold (IAnT) is an important step in the on-going development of these energy systems, especially the anaerobic glycolytic and oxidative metabolic processes. Without an accurate determination of swimming pace, heart rate (HR) and blood lactate concentration [HLa] at the IAnT for every swimmer, a coach cannot be certain of the relative intensity of any particular training session.

Coaches should endeavour to use a scientific approach for each individual by establishing appropriate training thresholds. However, it is not feasible in terms of time or money for coaches to use sophisticated equipment at every session in order to establish appropriate training intensities for each individual swimmer.

There are a number of tests available which can be used to determine an IAnT value (8,15,21). However, all of these require either the measurement of [HLa] or
ventilatory and oxygen uptake (\(\dot{V}O_2\)) responses to predetermined workloads. The acquisition of the necessary equipment and chemicals and/or paid assistance to make these measurements proves too expensive for most coaches. An alternative test has recently been developed by Cellini et al. (2) [based on Conconi et al. (3)], whereby coaches might be able to non-invasively determine the IAaN\(T\) by simply using a stopwatch, pool space and a HR counter.

Recent studies (18,20) have compared the original non-invasive protocol (3) to the invasive protocols of Mader, as cited by Heck et al. (8) and Stegmann et al. (15) for the exercise modes of running and running, rowing and cycling. However, no study to date has attempted to validate the non-invasive protocol for the exercise mode of swimming (2) against an invasive protocol (15) in which [HLa] responses are measured in a direct determination of the IAaN\(T\) exercise level. Therefore, the purpose of this study was to determine whether a non-invasive HR protocol is a suitable method of determining the IAaN\(T\) in swimmers.

Methods

Sample

Twelve volunteers (5 male, 7 female) ranging in age from 13 to 19 years (\(x \pm SE = 15.4 \pm 1.1\) years) were selected from a state level training squad. Subjects were required to attend a familiarization session where the procedures used to measure HR and for blood collection for the measurement of [HLa] were explained. All subjects gave their informed consent prior to participation and the study was approved by the Human Rights Committee of The University of Western Australia.

Experimental Procedures

The study consisted of two separate testing days for each subject. Both tests were held during the same week with a period of 48 hours between each testing session for all subjects. Each subject was randomly assigned to either the Cellini et al. (2) (hereafter the “non-invasive”) or Stegmann et al. (15) (hereafter the “invasive”) protocol on a particular day, to reduce any variability that may have occurred within subjects. All testing was carried out between 5.30 a.m. and 8.30 a.m. in a heated 25m outdoor pool. The temperature in the pool ranged from 27.5°C to 28.5°C and the relative humidity of the surrounding environment varied between 71% and 79%.

Anti-wave lane ropes were used at all times. Only one swimmer was tested in each lane during the determination of the IAaN\(T\) with either protocol.

The subjects involved in the study were required to abstain from eating (for 1 hour) and vigorous exercise prior to testing. On the first day of testing, measurement of body mass (± 10g), standing height and total skinfold thickness were obtained from eight sites. These characteristics of the subjects are presented in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The Physical Characteristics (x ± SE) of the Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>Height (cm)</td>
</tr>
<tr>
<td>Males</td>
<td>16.1 ± 1.0</td>
</tr>
<tr>
<td>(N = 5)</td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>14.1 ± 1.0</td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
</tr>
</tbody>
</table>

Each subject was then informed of the protocol to be employed and the use of three hand signals by the experimenters to control the subject’s pace when swimming. These signals were:

(a) Speed-up: arm extended, palm facing upwards, slowly raising arm,
(b) Maintain speed: thumbs up signal,
(c) Slow down: arm extended, palm facing downwards, slowly lowering arm.

The swimmers were instructed to always turn to a particular side (of their choice) after turning at each 50m (invasive protocol) or 25m (non-invasive protocol), to watch for hand signals. The rate of arm movement (when necessary) was varied to enable the subject to judge how much to increase or decrease speed.

During the testing HR were measured by use of a liquid crystal HR monitor with a digital readout (Department of Human Movement and Recreation Studies, The University of Western Australia) which allowed the measurement of exercise HR within five seconds of placement on the chest wall. The time for each swim effort was recorded via a hand held stop watch.

When appropriate, blood samples (50 μl) were collected from an ear lobe and measured for [HLa] using an Analox LM3 multichannel analyser. The same procedures as used by Gullstrand and Lawrence (7) were followed. The average coefficient of variance for serial sampling was 1.57%.

Day 1 and Day 2

The determination of the invasive individual anaerobic threshold (IAaN\(T\))

The invasive protocol (15), as used with cycle ergometry, involved incremental, graded exercise for three minute steady state workloads up to exhaustion. In this study this was achieved by utilizing a 300m swim. For accurate analysis, the test required a minimum of four workloads graded from easy to maximal. To accomplish this, each coach was asked to supply a recent best time over 300m for each swimmer. From this best 300m time, four times were calculated for successive 300m efforts as well as for each 50m split of each 300m swim.
These times were established by adding nine seconds to the given 300m time, within a nine second increase in successive 300m swims, thereby allowing a one to two second increase in pace over a 50m effort.

For example:

<table>
<thead>
<tr>
<th>Expected</th>
<th>Final 300m time</th>
<th>Third effort</th>
<th>Second effort</th>
<th>First effort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 min 37.0s</td>
<td>3 min 46.0s</td>
<td>3 min 55.0s</td>
<td>4 min 04.0s</td>
</tr>
</tbody>
</table>

By subtracting nine seconds from the final (fourth) 300m the time for a fifth 300m was established if required. Each subject was asked to be totally subjective in how they felt after the third and fourth 300m effort, in order to determine whether a further 300m effort was required. A subject only attempted a fourth or fifth 300m swim if they felt able to do so.

During each 300m effort, the time swum for each 50m split was recorded and this information was relayed to the swimmer via hand signals (to increase, decrease or keep steady the pace). Immediately upon completion of each 300m swim, the subject’s HR was also measured and blood collected for the measurement of [HLa]. There was a one minute interval between successive efforts during which the subject was further informed of the suitability of the pace of the 300m swim. Blood was also collected for measurement of [HLa] 2, 5 and 10 minutes after the final swim (15).

During the determination of the invasive IAnT, four subjects completed 5 x 300m swims, six completed 4 x 300m swims and two completed 3 x 300m swims. None of the subjects found it difficult to maintain the required pace for the first two of the successive 300m efforts. However, with some of the subjects only able to complete 3 x 300m swims, some discrepancy between the required and actual pace for the latter swims was evident.

The invasive IAnT was determined using the times swum and HR and [HLa] values measured during the test. These values were plotted on a graph on which two ordinates (HR measured in b*min$^{-1}$ and [HLa] measured in m mol$^{-1}$) and one abscissa (velocity measured in m$^2$s$^{-1}$) to represent a workload, were drawn (see Figure 1).

The graphing of velocity involved taking the 300m time and then dividing it by 300m to establish an average velocity (m$^2$s$^{-1}$). To comply with the original invasive IAnT protocol (15), the average velocity was cubed for a particular 300m effort and the swimming time converted to a workload (1,14).

By plotting [HLa] against cubed velocity a lactate (La) production curve was drawn and the IAnT established (15). A horizontal line was drawn from the highest [HLa] measured (after the termination of exercise). This cor-

![Figure 1: Determination of the invasive individual anaerobic threshold (IAnT) following the completion of 4 x 300m freestyle swims.](image)

Legend

- O: Blood lactate (La) versus velocity during the 4 x 300m freestyle swims and versus recovery time immediately after the final 300m effort and 2, 5 and 10 minutes post-exercise.
- X: Heart rate (HR) versus velocity during the 4 x 300m freestyle swims.
- A: Exercise terminated, point of maximal La accumulation.
- B: Recovery period, point when La concentration equals A.
- $E_m$: Tangent from point B, where $E_m$ contacts lactate curve C becomes IAnT.

responded to point A (see Figure 1). The point on the La recovery curve where this horizontal line intersected was nominated point B and from point B a tangent was drawn and was known as $E_m$. Where $E_m$ contacted the La production curve (point C) became the IAnT. A vertical line was then drawn from point C until it intersected the abscissa to establish the IAnT workload in m$^2$s$^{-1}$. Taking the cube root of the (m$^2$s$^{-1}$) value to obtain a value in (m$^2$s$^{-1}$), then dividing 100m by this (m$^2$s$^{-1}$) value, allowed the prediction of a 100m time at the IAnT in minutes and seconds.

For example:

\[
\text{Velocity at IAnT} = 1.66 \text{ m}^2\text{s}^{-1}
\]

\[= \sqrt[3]{1.66} \]

\[= 1.18 \text{ m}^2\text{s}^{-1} \]

\[= \frac{100}{1.18} \]

\[= \text{1 min 24.7 s} \]

Drawing a horizontal line to the tangent (point C) at the IAnT allowed the establishment of an associated [HLa] value at the IAnT.

Having determined an average velocity for each 300m effort, it was possible to plot an associated HR for each 300m effort. After the IAnT was established and the vertical line at the IAnT (Point C) extended until it bisected the HR curve, the associated HR at the IAnT was determined (Figure 1).
The determination of the non-invasive individual anaerobic threshold (IA\textsuperscript{T}N)

Based on the Cellini et al. (2) study, a series of graded slow to fast, 10-15 x 50m freestyle swims were used, with a 10 second pause between each 50m effort to measure HR and record swimming time. An accurate description of the exact number of 50m efforts completed by their subjects, or of the magnitude of increase in speed made with each successive 50m effort was not included by these authors. Hence, a test protocol was developed based upon the concept outlined by Cellini et al. (2) (i.e. increase in speed every 50 metres).

On arrival at the pool each subject was informed about the procedure of the 10-15 x 50m freestyle swims and asked what time he/she expected to swim for the final 50m. This formed the basis of the calculation of the times required for each of the 50m efforts by adding two seconds to the time required for each successive 50m effort.

For example: expected final time \(-30s\)

Thus, second last effort \(-32s\)
third last effort \(-34s\)
fourth last effort \(-36s\)

etc.

Initially, times were calculated for 15 x 50m freestyle swims, for each individual subject, however the final number of 50m efforts completed depended upon the effectiveness of each subject to maintain a two second drop in successive 50m efforts and their ability to reach the final predetermined 50m time.

During the determination of the non-invasive IA\textsuperscript{T}N two subjects completed 13 x 50m swims, three completed 12 x 50m swims, four completed 11 x 50m, two completed 10 x 50m swims and one completed 9 x 50m swims.

Although none of the subjects found it difficult to begin the non-invasive IA\textsuperscript{T}N protocol, all subjects found it very arduous to maintain a constant two second drop between successive 50m efforts, with the greatest difficulties arising during the final seven efforts of the total number of 50m swims completed.

Using the time swum and HR measurements the non-invasive IA\textsuperscript{T}N was determined. On the graph, one ordinate (HR, b\textsuperscript{min}\textsuperscript{\textsuperscript{-1}}) and one abscissa (velocity, m\textsuperscript{s}\textsuperscript{\textsuperscript{-1}}) were drawn (see Figure 2).

The time swum for a 50m effort was converted to a velocity (m\textsuperscript{s}\textsuperscript{\textsuperscript{-1}}) by dividing 50m by the time in seconds for the 50m effort. The velocity was then cubed in accordance with Astrand and Rodahl (1) and Stegemann (14).

By plotting velocity against HR for every 50m effort and drawing a line of best fit, the point at which the HR/velocity curve departed from linearity became the non-invasive IA\textsuperscript{T}N, (point A).

![Figure 2: The determination of the non-invasive individual anaerobic threshold following the completion of 9 x 50m freestyle swims.](image)

Legend

\(X\) Heart rate/velocity relationship determined during 9 x 50m freestyle swims.

\(A\) Point of intersection where heart rate/velocity curve departed from linearity.

Analysis of Data

Data were analysed by a Pearson Product Moment Correlation coefficient, using the HR and swim velocity established during the invasive protocol versus the HR and swim velocity determined during the non-invasive protocol. The \(P < 0.05\) limit was adopted for determining statistical significance.

Results

The physical characteristics of the 12 subjects who completed the study are presented in Table 1.

Table 2 presents the swimming velocity, HR and [HL\textsubscript{a}] data recorded for the determination of the IA\textsuperscript{T}N by the non-invasive and invasive protocols.

Of the 12 subjects tested using the non-invasive protocol, six displayed clear breakpoints in their HR/velocity curves, four had breakpoints which were difficult to determine, and two had no breakpoints at all. As a result the curves of these two subjects were excluded from the statistical analysis.
Table 2
Mean (± SE) Swim Velocity (V), Heart Rate (HR) and Blood Lactate Concentration (HLA) Values Recorded Using the Invasive Individual Anaerobic Threshold (IAnT) and the Non-Invasive IAnT Test Protocols.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Invasive IAnT</th>
<th>Non-invasive IAnT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V (m.s⁻¹)</td>
<td>HR (b.min⁻¹)</td>
</tr>
<tr>
<td>1 (f)</td>
<td>1.78</td>
<td>192</td>
</tr>
<tr>
<td>2 (f)</td>
<td>3.25</td>
<td>210</td>
</tr>
<tr>
<td>3</td>
<td>2.46</td>
<td>180</td>
</tr>
<tr>
<td>4 (f)</td>
<td>2.31</td>
<td>184</td>
</tr>
<tr>
<td>5 (f)</td>
<td>2.35</td>
<td>188</td>
</tr>
<tr>
<td>6</td>
<td>2.37</td>
<td>184</td>
</tr>
<tr>
<td>7</td>
<td>2.40</td>
<td>186</td>
</tr>
<tr>
<td>8 (f)</td>
<td>1.58</td>
<td>194</td>
</tr>
<tr>
<td>9 (f)</td>
<td>2.05</td>
<td>163</td>
</tr>
<tr>
<td>10</td>
<td>1.93</td>
<td>192</td>
</tr>
<tr>
<td>11 (f)</td>
<td>1.92</td>
<td>192</td>
</tr>
<tr>
<td>12</td>
<td>3.08</td>
<td>176</td>
</tr>
<tr>
<td>X</td>
<td>2.29</td>
<td>187</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.47</td>
<td>11</td>
</tr>
</tbody>
</table>

Note: (i) The results of only 10 subjects are included here for the non-invasive IAnT as two subjects failed to record a breakpoint in their HR/velocity curves.
(ii) (f) denotes female subject.

Of the 12 subjects tested using the invasive protocol all showed similar La recovery curves. However, they were unlike those found in the original invasive study (15). In the present study, the curves demonstrated a rapid La removal curve post-exercise, which produced a much steeper recovery curve than shown previously (15).

A non-significant correlation of \( r = -0.09 \) \((P > 0.05)\) \((n = 10)\) was found between the non-invasive IAnT HR and the invasive IAnT HR. The mean \( \pm SE \) HR for the invasive IAnT was found to be higher \((187 \pm 11 \text{ b.min}^{-1})\) than for the non-invasive IAnT \((172 \pm 10 \text{ b.min}^{-1})\) even though the mean \( \pm SE \) velocity for the invasive IAnT was slower \((2.29 \pm 0.47 \text{ m.s}^{-1})\) than the non-invasive IAnT velocity \((2.38 \pm 0.62 \text{ m.s}^{-1})\). A non significant correlation of \( r=0.455 \) \((P > 0.05)\) \((n = 10)\) was recorded between these two velocities. Table 3 presents the required and recorded swim times for the 300m and 50m swim efforts. While no statistical analysis was performed on this data, it is evident that the subjects were able to maintain a more suitable pace with respect to that required during the longer 300m efforts. When performing the 50m efforts, the subjects found it very difficult to produce times close to those required, especially over the final 6-7 efforts.

**Discussion**

The low correlation recorded between the IAnT HR and velocity values determined in the two tests is likely to have resulted from the short, 50m distance used in the non-invasive protocol. A 50m distance is unlikely to have been long enough to enable a constant submaximal exercise HR to be established at each graded speed. Elliot et al. (5) found that HR during rallies in tennis matches were slightly, but significantly, lower than those recorded in the subsequent recovery period. They considered that the brief exercise period did not allow the HR sufficient time to reach its true exercise level, resulting in a "catch up" phase during the recovery period. A similar phenomenon may have occurred here. Keskinen et al. (10) also found that a 100m swim effort was too short a distance to achieve a steady state HR. They also stated that HR values measured after 100m, 300m or 400m swim efforts (at the same velocity) compared well at slower speeds, but not at faster speeds. In contrast, the 300m efforts used in the invasive protocol would have provided a better opportunity for the subjects to exercise at a constant pace and reach a more constant exercise HR. The 100m split times for the 300m efforts (Table 3) provide some evidence that this was the case.

Table 3
Mean (± SE) Required and Recorded Times for the 300 Metre (Invasive Protocol) and 50 Metre (Non-Invasive Protocol) Swim Efforts

<table>
<thead>
<tr>
<th>Swim</th>
<th>Invasive Protocol</th>
<th>Required Time (sec)</th>
<th>Recorded Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First 100m</td>
<td>100m</td>
<td>100m</td>
</tr>
<tr>
<td>300m (n=12)</td>
<td>83.0 ± 4.2</td>
<td>83.2 ± 4.9</td>
<td>84.9 ± 5.1</td>
</tr>
<tr>
<td></td>
<td>Second 100m</td>
<td>79.5 ± 4.8</td>
<td>81.9 ± 4.3</td>
</tr>
<tr>
<td>300m (n=12)</td>
<td>77.0 ± 4.2</td>
<td>76.2 ± 4.8</td>
<td>81.6 ± 4.5</td>
</tr>
<tr>
<td></td>
<td>Third 300m</td>
<td>74.0 ± 4.2</td>
<td>73.7 ± 4.5</td>
</tr>
<tr>
<td>300m (n=10)</td>
<td>74.0 ± 4.2</td>
<td>73.7 ± 4.5</td>
<td>76.4 ± 5.0</td>
</tr>
<tr>
<td></td>
<td>Fourth 300m</td>
<td>71.0 ± 5.8</td>
<td>70.1 ± 4.7</td>
</tr>
<tr>
<td>50m (n=4)</td>
<td>37.0 ± 3.0</td>
<td>15.8 ± 6.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eighth 50m</td>
<td>35.0 ± 3.0</td>
<td>15.9 ± 6.6</td>
</tr>
<tr>
<td>50m (n=12)</td>
<td>33.0 ± 2.0</td>
<td>15.7 ± 2.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ninth 50m</td>
<td>31.0 ± 2.0</td>
<td>14.5 ± 2.9</td>
</tr>
<tr>
<td>50m (n=11)</td>
<td>30.0 ± 2.0</td>
<td>33.5 ± 2.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tenth 50m</td>
<td>29.0 ± 3.0</td>
<td>33.6 ± 3.0</td>
</tr>
<tr>
<td>50m (n=5)</td>
<td>27.0 ± 1.0</td>
<td>31.5 ± 6.7</td>
<td></td>
</tr>
</tbody>
</table>

*For the first six 50m efforts the subjects were able to record \( X \) ± SE times within 0.4 ± 0.2s of the required time.

Apart from the HR response to the 50m efforts, the distance of these swims may have been too short to prevent subjects from being erratic in their ability to maintain a constant speed. All subjects encountered some difficulty in maintaining the required increase in speed of successive 50m swims, particularly over the final seven efforts (see Table 3). The discrepancies between the required and recorded times over the latter 50m efforts may explain why the recorded HR values were lower for the non-invasive IAnT than for the invasive IAnT. However, this might reasonably be expected to occur, due to the shorter distance being swum.
The Non-Invasive Protocol

The 10-15 x 50m test protocol used in this study was developed and based on the work of Cellini et al. (2). However, their test protocol could not be reproduced exactly, as precise details were not reported. For example, the increase in speed required for each successive 50m effort was not specified. This may be an important factor in explaining the results of this study, where 4 of the 12 subjects had HR/velocity break points which were difficult to determine, while 2 others had no break point at all. However, other studies (6,11,13,18,19,20) have all reported similar difficulties with at least some of their subjects, raising serious doubts about the efficacy of trying to determine the IAnT level by non-invasive means. The latter study (20) also correlated the HR at the IAnT as determined both invasively and non-invasively, as was done in the present study.

Urhausen et al. (20) used the exercise modes of running and rowing and reported correlations of \( r = 0.18 \) and \( r = 0.35 \) respectively, when comparing the Conconi et al. (3) HR breakpoint to the HR at the IAnT as determined by the original invasive protocol (15). Even lower correlations were found when the HR at the IAnT was determined by the Mader protocol [4 mMol.L\(^{-1}\), as cited by (8)], rather than Stegmann et al. (15).

Therefore, the very low, non-significant correlation found here between the HR at the IAnT as determined invasively and non-invasively, would support the findings of Urhausen et al. (20). A non-invasive determination of the IAnT by HR/velocity breakpoint measurement would seem to be an unreliable estimate of the IAnT when determined by [HLa] measurements.

The Invasive Protocol

It was also necessary to modify the original Stegmann et al. (15) protocol for use in this study, as it was based on cycle ergometer and treadmill exercise rather than swimming. As mentioned previously, the La recovery curves found here did not resemble those reported by (15) and Stegmann and Kindermann (16). In these studies peak [HLa] occurred about 3 minutes post-exercise, whereas in the present study peak [HLa] occurred more rapidly, being recorded about 1 minute post-exercise (see Figure 1). These differences in the kinetics of the La recovery curves may be due to variations in the amount of active musculature (upper versus lower body) and the improved venous return facilitated by the hydrostatic pressure of the environment.

However, despite these differences in the La recovery curves, the [HLa] values recorded in this study at the IAnT are similar to those reported (15,16) for subjects of similar age and training status. Therefore, some support for the suitability of the modified Stegmann et al. protocol (15), as used here, can be shown. Also, Hein et al. (9) have recently utilised a 5 x 400 yard swim test (with a 30 minute recovery between efforts) for determining the IAnT invasively and Keskinen et al. (10) have employed a 5-6 x 300m swim test (1 minute between efforts) for the same purpose.

Conclusion

The Stegmann et al. protocol (15) for the invasive determination of the IAnT was the criterion measure against which the Cellini et al. non-invasive protocol (2) was compared. The results found here showed that the IAnT determined by non-invasive (HR) methods did not correlate with the IAnT determined by invasive methods ([HLa]). The major reason for the lack of relationship between the two protocols would appear to be the short, 50 metre effort used in the non-invasive protocol. This is unlikely to have been long enough to allow for a constant submaximal exercise HR to be established at each graded speed.

As such, the Cellini et al. HR method of determining the IAnT (2), as modified and used in this study, is seen to be unreliable and cannot be recommended. If non-invasive determinations of the IAnT are going to be validly compared to invasive methods to determine their efficacy, then similar distances must be used and the chosen distance must be long enough (for swimming, approximately 300-400m) to allow a steady state HR to be achieved in each effort. This could be achieved by using a research design where only one test protocol is utilized, and both HR and La measures are employed to determine the IAnT.

Acknowledgements

We wish to express sincere appreciation to Julie Kilvington, David John, Phil Pope and Alexandra Roberts for the many hours they assisted at the poolside during testing, and to Joan Williams for the preparation of this manuscript.

References


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A Publication of the American Swimming Coaches Association

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Physiological Change in Novice Swimmers During Short Term Swim Training.

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Abstract  
Forty eight untrained novice swimmers participated in a six week competitive swim training study that investigated changes in submaximal and peak oxygen uptake, submaximal blood lactate concentration, muscular strength and power, and swimming performance. Training groups were ages 6-8, 9-10, 11-12, and 13-17 years. A total of 93%, 71%, 55%, and 44% of training for the respective groups was directed toward technique instruction with the remaining training prescribed for rigorous physical conditioning. Submaximal oxygen uptake, blood lactate concentration, and performance time decreased in all groups, whereas muscular strength and power increased in all groups, p ≤ 0.05. Furthermore, peak oxygen uptake increased in the 11-12 and 13-17 age groups. The results of this study demonstrate that swimming training which emphasizes technique instruction is effective for evoking physiological and performance changes in untrained novice swimmers during the initial weeks of training.

INDEX TERMS: beginning swim training, technique instruction, propulsive efficiency

Introduction  
Anecdotal evidence from experienced coaches suggests that novice swimmers rapidly increase their tolerance to physical exercise during the early weeks of a competitive swim training season. As a consequence, performance also improves rapidly during this time. Many coaches attribute these improvements to the effect of intense physical conditioning. However, virtually no literature exists substantiating the effect of short term training on the physical capacity and performance of untrained novice swimmers. Since swimming is a specific mode of exercise that requires basic skills to perform at a minimal level, research directed at investigating the effect of swim training typically involves experienced swimmers and is usually of long duration (2,3,9,14,19,22,23,24). Only Vaccaro and Clark 1978 (22), and Clark and Vaccaro 1979 (2) have reported the effect of training on novice swimmers beginning a training program. However, their study investigated change at the beginning and end of a seven month training period.

Additionally, a detailed description of the training protocol used to evoke change in swimmers has not been reported, other than reporting overall daily training distances and the number of weekly training sessions (2,10,19,22,24). A need exists to better understand the effect of swim training on novice swimmers particularly in light of the fact that chronic intense physical conditioning during the early years of competitive swimming is suggested as a cause for the increased incidence of orthopedic shoulder problems and high attrition rate or “burn out” observed in age group swimmers (12,13). An effective training protocol to improve physical capacity and at the same time prevent injury and attrition could be one that places greater emphasis on technique instruc-
tion. Supporting this theory is a recent investigation of 473 developing elite swimmers with a history of shoulder pain who reduced the pain significantly when their stroke technique was altered (13). Therefore, this study was designed to investigate the effect of a short term swim training regimen that employed a significant percentage of technique instruction on the physiological capacity and competitive swimming performance of untrained novice swimmers.

Methods

Subjects: Forty-eight subjects, ages 6-17 years, from a competitive summer swimming team voluntarily participated in a six week swim training study. Adherence to the training program was extremely high with a minimum of 95% attendance for all subjects. Subjects were grouped for training purposes according to age related competition groups. Thirteen subjects ages 6-8 comprised training group A; 14 subjects ages 9-10 were in group B; 13 subjects ages 11-12 were in group C; and 8 subjects ages 13-17 comprised group D. All subjects were untrained novice summer swimmers who did not train or compete in swimming during the winter months, although all subjects trained and competed for this team a minimum of two previous summers with the exception of two six year old subjects who trained one previous summer. Physical characteristics of subjects are shown in Table 1.

<table>
<thead>
<tr>
<th>TRAINING GROUP</th>
<th>A</th>
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<tbody>
<tr>
<td>Height (cm.)</td>
<td>128.5 ± 3.5</td>
<td>143.2 ± 3.9</td>
<td>152.2 ± 6.7</td>
<td>170.3 ± 3.3</td>
</tr>
<tr>
<td>Weight (kg.)</td>
<td>26.9 ± 3.5</td>
<td>32.0 ± 2.1</td>
<td>40.7 ± 8.5</td>
<td>60.7 ± 3.3</td>
</tr>
</tbody>
</table>

Testing: Physiological and performance variables were measured at the end of the first week of training and again six weeks later following the swimming championships. Physiological testing did not begin prior to the first week of training as this time was needed to familiarize the subjects with the testing procedures. Strength (ST) and power (POW) of the arm and shoulder girdle were measured on one day, with submaximal oxygen uptake (SVO₂), blood lactate (Lₐ), and peak oxygen uptake (PVO₂) measured on the following day.

Strength and Power

Strength and POW of the arm and shoulder girdle were measured using a dry-land Biokinetic Swim Bench (Biokinetics Inc. Berkeley, CA.). Subjects were familiar with the apparatus as a similar swim bench was used to teach stroke technique during previous summers. However, prior to actual testing, subjects were instructed to perform two practice trials to familiarize themselves with the testing procedure. Strength was measured while subjects completed three maximal effort freestyle arm strokes with each arm in an alternating manner. The elbow was elevated above the level of the hand throughout the arm movement to better simulate proper pulling technique. The greatest amount of work performed in a single arm stroke was recorded as the subject’s maximal ST. To measure POW, the subjects continuously stroked with an alternating freestyle arm movement for 30 s. The total amount of work performed in 30 s was used as the power output. Arm stroking and recovery motions for both ST and POW tests were performed beneath the midline of the body.

Submaximal Oxygen Uptake and Blood Lactate

Submaximal oxygen uptake was measured using a tethered swimming ergometer. Subjects were familiarized to the procedure by swimming "in place" against a mild resistance for 1-2 min. A warmup resistance was then added to the ergometer for 2 min, after which the subject swam at a prescribed submaximal intensity for an additional 4-6 min. From previous testing with this subject sample, it was determined subjects in A, B, C, and D could tolerate a resistance of 0.75, 1.25, 1.50, and 2.00 kg, respectively, for a 4-6 minute period. During the test, subjects expired through a two way valve (Rudolph 2600), connected by tubing, into a 3 liter mixing chamber. Expired gas was collected from the chamber during the last 30 s of each min and analyzed by an Applied Electrochemistry S-3A and a Beckman LB-2 gas analyzer for percent O₂ and CO₂, respectively. Inspiratory volumes were measured with an automated ventilation module (Alpha Technologies, VMM-2. Laguna Hills, CA.). Subsequent PVO₂ tests for the two older age groups indicated these resistances elicited approximately 70% PVO₂ (68% to 73%). Two min following the test, 25 microliters of blood was drawn from the finger-tip for determination of Lₐ concentration (mM) using an automated lactate analyzer (Yellow Springs Instrument 23L). Test-retest of this procedure showed it to be very reliable with an r²=0.9967.

Peak Oxygen Uptake

Approximately 20 min following the SVO₂ test, subjects in groups C and D swam a warmup and were then instructed to complete a maximal effort evenly paced 200 y (183 m) freestyle swim to measure PVO₂. Subjects in group A and B were unable to perform a 183 m swim in an evenly paced manner and therefore were not tested for PVO₂. Immediately upon completion of the swim a breathing mask (Rudolph 7900) was placed over the face and 20 s of expired gas was collected for determination of PVO₂ (18). All VO₂ tests were performed using the freestyle stroke.
Performance Swims

Time for a 25 m freestyle swim was used as the performance variable for group A, whereas time for a 50 m freestyle swim served as the performance variable for the other three training groups. Swimming times were obtained during competition by three timers using Accusplit digital stopwatches with the average time used as the official time.

Training Regimen: Training sessions were scheduled Monday through Saturday with groups A, B, C, and D practicing for 45, 60, 90, and 90 min daily, respectively. The mean ± SD daily swimming distance was 627 ± 175, 939 ± 198, 1808 ± 406, and 3018 ± 665 m, respectively, during 36 workouts. Daily training was organized into technique instruction and physical conditioning components. Technique swims ranged in distance from 25-75 m with 1-3 min of rest separating each swim. Previous experience with this group of subjects revealed these distances were effective for improving stroke technique without causing fatigue. Racing starts and turns were also practiced daily. Conditioning swims on Monday through Friday consisted of intervals of 25-75 m for groups A and B and 25-100 m for groups C and D. Work to rest ratios for A and B were 1:4:5 with a ratio of 1:3:4 for the two older groups. Practice on Saturday was designed for "high quality supramaximal freestyle sprinting". Training on this day included a warmup, then one set of 6x25, 5x50, 7x50, or 10x50 m maximal effort freestyle swims for groups A, B, C, and D, respectively, and a cooldown. Work to rest ratios on Saturdays were never less than 1:8 for any age group. A continuous aerobic swim of 200-300 m and 500-1000 m was also performed twice weekly by groups C and D. To qualify the intensity of practices, subjects in groups B, C, and D monitored heart rates by palpation every other training day following each component of practice. These swimmers were very experienced in palpation as this was typically used in previous years to monitor recovery. Heart rates for group A were palpated by experienced older swimmers and coaches. However, their results were very similar to those taken by the young subjects in group A. Each group's mean swimming distance and heart rates for the practice components are shown in Table 2 with the percentage of total daily swimming for the components illustrated in Figure 1.

![Image](https://example.com/image.png)

Figure 1. Percentage of daily training distance devoted to technique instruction and physical conditioning.

Statistical Analysis: A multivariate analysis of variance (MANOVA) was used to analyze change in $SVO_2$, $L_a_b$, ST, POW, and performance times. When a significant difference was established, a univariate analysis was performed on the individual variables, $p \leq 0.05$. Since C and D were the only age groups performing the PVO2 tests, this was not included in the MANOVA and was analyzed using univariate analysis, $p \leq 0.05$.

Results

The effect of the training protocol on the physiological variables is shown in Table 3 with performance times shown in Table 4. Analysis detected that $SVO_2$ and $L_a_b$

<table>
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<tbody>
<tr>
<td>Swimming Distance (m)</td>
<td>574 ± 150</td>
<td>662 ± 151</td>
<td>1005 ± 228</td>
<td>1326 ± 305</td>
</tr>
<tr>
<td>Heart Rate (bpm)</td>
<td>140 ± 14</td>
<td>140 ± 15</td>
<td>135 ± 18</td>
<td>140 ± 9</td>
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* Significant change, $p \leq 0.05$. BT = before training, AT = after training

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<tbody>
<tr>
<td>$SVO_2$ BT</td>
<td>34.32 ± 4.37</td>
<td>40.11 ± 3.17</td>
<td>32.05 ± 7.47</td>
<td>38.65 ± 5.28</td>
</tr>
<tr>
<td>$L_a_b$ BT</td>
<td>2.32 ± 0.64</td>
<td>4.86 ± 1.63</td>
<td>5.55 ± 1.04</td>
<td>5.90 ± 1.49</td>
</tr>
<tr>
<td>ST BT</td>
<td>17.31 ± 9.93</td>
<td>28.82 ± 13.57</td>
<td>48.40 ± 16.82</td>
<td>99.65 ± 38.66</td>
</tr>
<tr>
<td>POW BT</td>
<td>3.29 ± 2.59</td>
<td>8.50 ± 4.04</td>
<td>11.41 ± 3.49</td>
<td>24.96 ± 10.63</td>
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Table 2: Mean ± SD Swimming Distance and Heart Rates of Technique Instruction (T) and Conditioning (C) Components of Practices

<table>
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<tbody>
<tr>
<td>$SVO_2$ BT</td>
<td>29.29 ± 3.56*</td>
<td>33.02 ± 4.61*</td>
<td>25.92 ± 7.37*</td>
<td>31.61 ± 5.66*</td>
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<tr>
<td>$L_a_b$ BT</td>
<td>2.34 ± 0.31*</td>
<td>3.83 ± 1.10*</td>
<td>2.98 ± 1.32*</td>
<td>2.99 ± 0.75*</td>
</tr>
<tr>
<td>ST BT</td>
<td>27.94 ± 13.18*</td>
<td>44.37 ± 14.85*</td>
<td>44.17 ± 35.41*</td>
<td>154.93 ± 78.50*</td>
</tr>
<tr>
<td>POW BT</td>
<td>3.76 ± 3.78*</td>
<td>10.71 ± 3.92*</td>
<td>16.17 ± 4.43*</td>
<td>38.79 ± 18.21*</td>
</tr>
</tbody>
</table>

* Significant change, $p \leq 0.05$. BT = before training, AT = after training

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<tbody>
<tr>
<td>$SVO_2$ BT</td>
<td>26.79 ± 6.78</td>
<td>46.47 ± 8.57</td>
<td>38.21 ± 2.83</td>
<td>32.41 ± 2.00</td>
</tr>
<tr>
<td>$L_a_b$ BT</td>
<td>23.74 ± 4.74*</td>
<td>44.34 ± 7.23*</td>
<td>36.32 ± 2.96*</td>
<td>30.01 ± 2.91*</td>
</tr>
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</table>

* Significant change, $p \leq 0.05$. BT = before training, AT = after training

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<tr>
<td>$L_a_b$ BT</td>
<td>23.74 ± 4.74*</td>
<td>44.34 ± 7.23*</td>
<td>36.32 ± 2.96*</td>
<td>30.01 ± 2.91*</td>
</tr>
</tbody>
</table>

Table 3: Mean ± SD for Submaximal Oxygen Uptake in ml·kg⁻¹·min⁻¹, Blood Lactate in mM, Strength in Newton-Meters, and Power in Watts

Table 4: Mean ± SD Time (s) for the 25 m (Group A) and 50 m (Group B,C,D) Freestyle Performance Swim
significantly decreased, and ST and POW significantly increased in all groups during the six week training period. The decrease for each group in SVO₂ of 14.6, 17.6, 19.1, and 18.2%, and an increase in ST of 62.0, 54.0, 51.2, and 53.3%, respectively, demonstrates the ratio of technique instruction to physical conditioning for each age group was effective for improving these variables similarly. Conversely, a magnitude greater decrease in Lₐo of 46.3% and 48.5% for group C and D compared to 27.1% and 21.1% for A and B reflects the effect of increased physical conditioning on blood lactate accumulation. There was no trend in muscular power improvement for the arm and shoulder girdle as group A, B, C, and D improved 75.0, 26.0, 41.7, and 55.4%, respectively. PVO₂ increased in groups C and D, from 44.1 ± 4.0 to 49.1 ± 3.2 and 43.1 ± 6.5 to 51.7 ± 7.1 ml·kg⁻¹·min⁻¹, respectively, p ≤0.05. Finally, performance times improved for groups A, B, C, and D by 11.4%, 4.6%, 4.4%, and 4.3%, respectively.

Discussion

The results of this study demonstrate that untrained novice swimmers improve physiological capacity and performance during the initial weeks of a competitive swim training regimen. An analysis of the training protocol shown in Figure 1 indicates that 93, 71, 56, and 44% of total training for groups A, B, C, and D, respectively, was directed toward technique instruction with the remaining swimming in each group directed toward physical conditioning. The difference, across the age groups, in the amount of training devoted to technique or conditioning training was a function of the coaches’ experience that the most effective training protocol for novice swimmers who are beginning training is one that emphasizes technique instruction proportionately more in younger versus older swimmers. An analysis of the previous eight year’s training regimen for this team indicated consistently similar quantities of technique instruction across the age groups as that observed in this study.

A limitation of this study could be that a control group was not included. Initially an attempt was made to test control subjects. However, because swimming requires basic skills and conditioning to perform at a minimal level, nonswimmers were unable to perform the SVO₂, PVO₂, ST, and POW tests properly. The intent of this study was to investigate the efficacy of the training program on physiological markers of swim performance and performance itself in untrained novice swimmers. The authors therefore believe that the lack of a control group does not diminish the findings of the experimental training regimen.

The effect of short term swim training on ST and POW of the arm and shoulder girdle in untrained swimmers is unknown. In the swimming study by Clark and Vaccaro, whole body strength measured by combined grip, back, and leg lift strength did not significantly improve during seven months of swimming training (2). The techniques used to measure strength in Clark and Vaccaro’s study were not specific to the movement patterns of swimming and consequently strength and power gains of swimming musculature could have been masked. Conversely, in the present study, ST and POW were assessed on the swim bench which allowed the swimmers to mimic movement patterns very similar to actual swimming motion. It is understandable that the specificity of testing used in this study allowed changes in ST and POW to become more apparent.

The ability of the swimmers to generate a greater propulsive force as a result of technique training is another factor suggested as responsible for the improvement in ST and POW of the arm and shoulder girdle. Previous investigators have demonstrated that swimming propulsion is increased by improving the propulsive efficiency of arm stroke mechanics (5). To improve efficiency, swimmers practiced multiple swimming drills, daily, to perfect an arm stroke pattern performed in a zig-zag curvilinear three-dimensional reference frame with continual changes in hand pitch and hand velocity. The hand ‘weaves’ through the water accumulating large amounts of water on the palm of the hand. The increased volume of water provides an increased resistance against which the upper body musculature is able to perform more of an isokinetic contraction during the stroking pattern. Consequently, greater peak force is generated more often throughout the stroking pattern which in turn provides a greater stimulus for gains in ST and POW (15,17). Decreases in SVO₂ and Lₐo, which are often used as criteria for measuring swimming efficiency, support the conviction that technique instruction was effective for improving swimming efficiency (5,8). As swimmers learned to apply proper stroke technique, swimming efficiency increased and less aerobic and anaerobic energy was required to perform the same absolute work.

High intensity interval training similar to that utilized in the present study has also been shown to be effective for increasing ST and POW through neural adaptation. Repeated rapid muscular contractions against a high resistance similar to that produced during high velocity swimming increases the coordination and activation of prime movers, synergists, and antagonists (6,21). Studies have shown that youth exposed to high resistance training possess similar motor unit activation ability as adults and are able to develop about the same force per unit muscle cross-sectional area during a maximal voluntary contraction, especially in upper body musculature (Unpublished observations from the Human Performance Laboratory, McMaster University). Excluding aerobic swimming performed by groups C and D, the conditioning component for all age groups consisted primarily of repetitive high velocity interval and sprint swimming. Recorded sprint
times on Saturday approximating 95% of best competition time and heart rates taken after interval training of 85% of age predicted heart rate reserve support the fact that the conditioning training provided sufficient intensity and thus neural stimulus to enhance muscular ST and POW.

As expected, pre-training mean PVO₂ values of 44.1 and 43.1 ml·kg⁻¹·min⁻¹ for groups C and D, respectively, were lower than the reported VO₂max values for more experienced trained swimmers (4,14,16,19,23), but similar to those for untrained subjects of comparable age (11). Furthermore, the increase in aerobic power of 11.3 and 19.9% for groups C and D is consistent with changes observed in other studies with comparable amounts of training (20). Repetitive 75 and 100 m freestyle swims with short rest intervals were a principal aerobic training set for groups C and D, respectively. Interval training of this type has been shown to be effective for enhancing both anaerobic and aerobic capacities by placing high metabolic demands on both systems (1,7). Additionally, progressively longer continuous aerobic swims ranging from 200-1000 m were performed bi-weekly to further enhance aerobic capacity (1). Nonetheless, the effect of training on aerobic capacity in pre-pubescent and pubescent youth is confounded by growth and maturation. Several investigators have reported increases in absolute and relative VO₂max beyond that attributed to growth during training (22,24), whereas other investigators have reported no training effect on relative VO₂max above that attributed to growth (10). Since no significant change in height and weight occurred in any group of subjects in the present study, it is suggested that training and not growth or maturation contributed to the increased PVO₂.

**Practical Application**

The intent of this study was to investigate the effect of short term swim training on the physical capacity and performance of novice swimmers who were beginning a training season. An additional intent was to describe the training protocol used to evoke any change. The results demonstrate a low yardage training protocol that emphasizes technique instruction is very effective for improving swimming performance, muscular strength and power, maximal aerobic capacity in older ages, and swimming efficiency exhibited by decreases in submaximal oxygen uptake and blood lactate. This is particularly apparent in training groups A,B, and C where total daily training consisted of an average of only 625, 940, 1800 m, respectively, and was predominantly technique instruction. Likewise, analysis of the training protocol for group D shows that approximately half of total training was technique instruction and only 1700 m were devoted to conditioning, which anecdotally is not a great amount of physical training for this age group in a 90 min session. The results should assure coaches that practices geared toward stroke improvement will improve performance and physical capacity.

The authors have discussed how the improvement in swimming efficiency could increase strength and power. Knowing that shoulder injury is prevalent in the sport of swimming and is caused by overuse, it is important for coaches to comprehend that novice swimmers, regardless of age, benefit as much from low yardage technique instruction as high yardage physical training. The rationale or implication for including a large amount of technique instruction in workouts is that stroke instruction improves stroke efficiency which in turn allows a swimmer to produce a greater force against the water. Consequently, the swimmer is able to swim faster without swimming an excessive amount of yardage. This becomes a feedback cycle in that as a swimmer become faster he/she also becomes stronger in the shoulder girdle. Increased strength around the shoulder joint then becomes a deterrent to overuse injury.

Inspection of Figure 1 shows the percent of technique instruction decreased and physical training increased as the age of the training groups increased. However, similar changes were observed across the age groups for SVO₂, ST, and performance suggesting this type of training ratio was very effective. Therefore, a swimming regimen devoted to stroke development seems to be effective during the initial stages of swimming training. Once proper technique is established, additional physical conditioning can then be integrated with ongoing technique instruction as the swimmer matures. This approach to swim training in novice swimmers seems more appropriate particularly in light of the reported incidence of joint problems and the high attrition rate attributed to excessive overtraining in age group competitive swimmers. To that end, our findings agree with recent investigations on older more experienced swimmers that extensive physical training is not paramount for improving swimming performance or provoking change in physiological variables associated with performance (3,9).

**Acknowledgements**

Appreciation is given to Dr. David Lamb and the Exercise Physiology Laboratory and Richard Sloan, Mens Swimming Coach (retired) at the Ohio State University for the use of their facilities in data collection. This project was funded in part by Yellow Springs, Inc.

**References**

A Nutrition Guidebook to Improve the Diet of Male and Female Collegiate Swimmers

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Abstract

Six male and nine female Division IAA collegiate swimmers participated in a study to test the ability of a nutrition guidebook to improve the quality of their normal diet. Subjects monitored their diet by recording food group servings in the guidebook for one week. Next, a guidebook-tailored personalized plan was given to each subject that met energy needs and provided 65% of kilocalories as carbohydrate (CHO), 13% as protein and 22% as fat; subjects were asked to follow this plan and monitor their new diet using the guidebook for one week. Questionnaire results revealed that subjects found the guidebook fairly to moderately easy to use, but remembering to record food servings and estimating serving sizes hindered strict interpretation of its effectiveness. Subjects were surprised by the amount of food they were encouraged to eat while following their personalized plans, especially of fruits, vegetables, and fat. Diet monitoring revealed that when eating their normal diets, females ate only 61% of their calculated CHO and energy needs. When following their personalized plans, females significantly improved their intake of CHO and total energy, which increased to 75% and 76% of needs, respectively. Males, on average, normally consumed sufficient food to meet their energy and macronutrient needs, but low energy intake in 3 of the 6 men caused significant variation in the data. When following their personalized plans, males continued to meet their needs but the variation observed while eating their normal diets was reduced considerably. By insuring the consumption of a well-balanced diet for optimal swim performance, the HEALTHY EATING guidebook has been shown to be a valuable tool for male and female collegiate swimmers.

Introduction

Today's athletes are advised to consume a nutritionally-balanced, high carbohydrate diet. Some athletes are even aware of the recommendation that they consume a diet that provides 12% to 15% of total energy as protein (PRO), 25% to 30% as fat (FAT) and 55% to 65% as carbohydrate (CHO) (2). To make use of this recommendation, athletes must clear 2 hurdles. First, they must know their energy needs and second, they must be able to translate the recommended macronutrient percentages into breakfast, lunch and dinner. To assist athletes in clearing both hurdles, a nutrition guidebook was developed specifically for athletes and tested on Division IAA collegiate swimmers (6). Studies have shown that competitive swimmers could benefit from nutrition advice: female swimmers have been reported to consume less than optimal levels of carbohydrate and energy (3,5,22), and poor carbohydrate intake has been shown to impair swim performance in males (10). The goals of this study were to provide each swimmer with a nutrition guide that met the recommendations for an optimal diet for an athlete, and to determine the guidebook's ability to improve the swimmers' normal diet.

Methodology

The HEALTHY EATING guidebook is an easily transportable, 6" by 9", brightly colored booklet. Each page lists foods and their serving size that belong to one of six food categories, modeled after the Diabetic Exchange List (1). The six food categories are fruits, vegetables, meat and meat alternates, milk and milk products, carbohydrates, and fats and alcohol. A seventh category called "convenience foods" is located at the end of the booklet where combination and fast-foods are broken down into their component food categories (12,16). Macronutrient composition of all foods servings was verified (21) and the macronutrient profile of each food category was entered into a computer program to facilitate interconversion of food servings with energy and macronutrient consumption (7). The guidebook was
validated by four nutrition experts, using the criteria of Tuckerman (20).

Athletes monitor their diet by recording the number of servings of food they have eaten (see Figure 1). An "X", indicating 1 serving, or a "/2", indicating 1/2 serving, is placed under the appropriate food category and day of the week. When a specified macronutrient and caloric intake is desired, the daily number of servings to be eaten from each food category are written into the "Daily Goals" row, and the user is encouraged to meet their "Daily Goals" from each food category.

<table>
<thead>
<tr>
<th>Daily Goals</th>
<th>FRUIT</th>
<th>VEGETABLES</th>
<th>FAT</th>
<th>MLK</th>
<th>MEAT</th>
<th>HIGH CHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
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<td>Tuesday</td>
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<td>Sunday</td>
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</tbody>
</table>

Figure 1. Sample of how to record food servings from the six food categories.

This study was divided into 2 phases, 8 weeks apart. In phase I (normal diet), all subjects attended a 45 minute workshop conducted by a licensed nutritionist (GC), and were instructed on measuring and estimating food serving sizes using food models, on how to use the guidebook, and were asked to monitor their usual diet for 7 days; this information was collected and analyzed for average daily energy intake and intake of CHO, PRO and FAT. Subjects were encouraged to record food servings immediately after eating if possible. All subjects answered a questionnaire, validated by four nutrition experts (20), to ascertain the subject’s comfort level at using the guidebook, their feelings about their energy level, and their attitudes toward nutrition.

During phase I, information was also collected on each subject's height, weight, age, and daily training regimen. Swim and weight training averaged two to three hours per day, 6 days per week. Two of the nine female subjects and two of the six male subjects were sprinters; all others were endurance swimmers. Energy needs were calculated for one week using the Harris-Benedict equation (13) and normal and sports energy expenditures (15), and divided by seven to estimate total daily energy needs. Each swimmer’s energy needs were converted to food category servings or "Daily Goals", using the computer program (7) and transcribed into each swimmers guidebook.

In phase II (athletes diet), guidebooks were returned to each subject. Subjects were asked to consume their "Daily Goals", and monitor their diet for 7 days during which time their training regimen was similar to that during phase I. This information was collected and analyzed as described for phase I. It was explained to the athletes that the goals represented an optimal diet for an athlete, providing 65% of energy needs as CHO, 13% as PRO and 22% as FAT, and that their Daily Goals were individually determined. Athletes were encouraged to continue targeting their Daily Goals after the 7-day recording period. At the end of phase II, subjects were asked to answer a validated questionnaire similar to the one used in phase I.

Average daily intake of energy, CHO, PRO and FAT was statistically analyzed within the females and male subject groups independently, using Student’s t-test (19). Significance level was 5 percent.

This study was approved by the University of New Hampshire's Institutional Review Board for Use of Human Subjects, which conforms to the policies of the US Dept. of Health, Education and Welfare and the American Physiological Society. In accordance with that approval, written consent was obtained from all subjects and all information was kept confidential.

Findings

Diet Improvement

Table 1 lists characteristics of the 15 subjects. All subjects had normal BMI, reported no change in body weight during phases I and II of this study, and were within the normal range for their ideal body weight although females desired to weigh an average of 4 kg less than actual.

<table>
<thead>
<tr>
<th>Subject Characteristics*</th>
<th>female</th>
<th>male</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>age, years</td>
<td>19.9 ± 1.0</td>
<td>19.5 ± 1.2</td>
</tr>
<tr>
<td>height, cm</td>
<td>168.5 ± 5.8</td>
<td>181.2 ± 6.6</td>
</tr>
<tr>
<td>weight, kg</td>
<td>64.0 ± 7.3</td>
<td>76.3 ± 9.6</td>
</tr>
<tr>
<td>BMI</td>
<td>22.5 ± 2.3</td>
<td>23.2 ± 2.0</td>
</tr>
<tr>
<td>desired wt, kg</td>
<td>60.2 ± 5.5</td>
<td>76.7 ± 8.5</td>
</tr>
<tr>
<td>% IBW</td>
<td>102 ± 10</td>
<td>103 ± 10</td>
</tr>
<tr>
<td>calculated energy needs, kcasls</td>
<td>3002 ± 165</td>
<td>3736 ± 296</td>
</tr>
</tbody>
</table>

Values are mean ± SD

During phase I, females ate significantly less than their calculated needs for all 4 categories: CHO, FAT, PRO and energy (open bars, Figure 2). The average female's energy intake was 1816 ± 412 kcallories, compared to calculated needs of 3002 ± 165 kcallories. Average intake of CHO was only 293 ± 67 grams, 60% of the
The average consumption of CHO, FAT, PRO, and energy for male subjects during phase I was not significantly different from calculated needs (open bars, Figure 3). However, there was considerable variation between subjects in this data, as the standard deviations ranged from 23% to 53% (those for females during phase I ranged from 13% to 24%). This variation was caused by 3 of the subjects who were consuming less than two-thirds of their caloric needs. Average number of food group servings consumed during phase I was 3 vegetables, 3.3 fruits, 11 carbohydrates, 7 milk and milk products, 6 meat and meat alternate and 14 fats. In phase II, when Daily Goals were provided, all 3 males improved their intake to 95% of calculated needs, and the group stan-
standard deviation was reduced to 7.1% to 18.7% (solid bars, Figure 3). Average number of food group servings consumed during phase II versus calculated serving goals were 5 vs. 6 vegetables, 5 vs. 9.5 fruits, 13 vs. 11.5 carbohydrates, 4 vs. 3 milk and milk products, 4 vs. 5 meat and meat alternates, and 16 vs. 14.5 fats and alcohol.

Guidebook Use

Questionnaire results revealed that it took an average of 4 days before subjects felt comfortable using the guidebook. Most of the men found the guidebook moderately easy to use, whereas most women found it easy to use; this gender difference may reflect the fact that none of the men had ever monitored their diet before, whereas 62% of the women had. It should be kept in mind that this “ease-of-use” assessment was totally subjective since the guidebook was not compared to other diet-monitoring tools, but of the women who had monitored their diet, all said the guidebook was easier than methods they had tried previously. The 2 major hurdles to using the guidebook were remembering to record food servings and estimating the size of food servings. Five of the 6 men reported having measured their food servings during phase II, whereas half of the women didn’t measure servings at all. This may reflect the women’s prior experience at monitoring their diet, but it may also have introduced error into their reporting of food group servings. Over 80% of subjects, however, reported recording what they ate either right after eating or at the end of each day.

Sixty-seven percent of the men and 80% of the women said that using the guidebook during phase II caused them to change their eating habits. Nearly all participants reported that the guidebook afforded them one or more benefits, the major ones being (1) an increased awareness of the nutritional composition of foods and their nutritional needs, (2) increased energy, and (3) increased endurance. A majority of subjects from both groups felt that nutrition has an influence on athletic performance (55% of males, 77% of females). When asked if they would change their diet to improve performance, even if it were difficult to do, 69% of females said they would change, whereas only 33% of males said they would do so.

Subjects were asked if there was anything about their “Daily Goals” in phase II that was unexpected. Eleven of the subjects responded that they didn’t expect their daily food servings, especially of fruits, vegetables, and fat, to be set so high. They were also surprised that their daily food servings of fat were nearly identical to those for carbohydrate. Half of the females felt the phase II diet had them eating too much food, but none of the males felt this way. Most (83%) of the males and half of the females felt that their goals provided them with just the right amount of food.

Discussion

The effectiveness of the HEALTHY EATING guidebook can be judged from 2 vantage points: what its users said and what its users did. In this study, the users said the guidebook was fairly to moderately easy to use, although they found it inconvenient to record what they ate and to estimate food serving sizes. As for what the users did, they appeared to use the guidebook to their advantage. Half of the male subjects and nearly all of the female subjects reported improvement in their diets. From this we conclude that the guidebook is an effective tool for improving the diets of swimmers.

Closer examination of nutrient intakes during the two phases of the study reveals some interesting gender differences. When eating their normal diet, the females reportedly consumed far less than their needs. Others have reported similar findings (5,22). When presented with “Daily Goals” however, the females in this study significantly improved their energy and carbohydrate intakes, although the intakes still remained below needs. Two points should be noted here. The first is under-reporting of food consumption. If under-reporting did occur, then subjects were consuming levels of energy and macronutrients that were closer to their needs, and our calculations are underestimates of their actual food consumption. Despite this, if under-reporting was constant throughout the study the effectiveness of the guidebook is still evident since a dietary improvement did occur in phase II. The second point is that the guidebook may have provided athletes with a degree of “permission” to eat more food. If so, this is an advantage especially for those athletes who tend to undereat or restrict their caloric intake.

The females in this study consumed fewer calories than reported in a similar study (14), but there was no reported change in body weight between phases I and II when energy intake reportedly increased. Changes in metabolic efficiency or resting energy expenditure may have prevented a loss of body weight, as a similar finding for female athletes was reported by Mulligan and Butterfield (17). Females in this study did report a desire to weigh less than their current weight, but eating behaviors of the subjects were not assessed. However, other studies report that female athletes show a higher incidence of weight-control behaviors than female non-athletes and males, and that their attitudes about weight are driven more by societal influences than by performance (4,11,23). This high incidence still exists but is less prevalent in sports where leanness is not overtly emphasized such as swimming and volleyball (4).

On average, male swimmers ate close to their calculated needs normally, as was observed in a similar study (14), but the guidebook’s benefit was evident with 3 of the 6 males who were undereating. All 3 improved when given specific goals to target in their eating.
Many athletes were surprised that their fat and alcohol "Daily Goals" were as high or higher than their carbohydrate "Daily Goals". The total kilocalories in 1 fat serving is 45 while those in 1 carbohydrate serving is 140. Psychologically, this serving equivalency but caloric discrepancy may be a disadvantage; athletes are accustomed to hearing that they should consume less fat and more carbohydrates. The guidebook may need to be modified in the future to take this into account.

In summary, the HEALTHY EATING guidebook can be a useful tool to educate swimmers about nutrition and to guide swimmers in monitoring their diets as they target specific dietary goals, with minimal time expenditure. This is particularly helpful for collegiate athletes with heavy time demands and limited opportunities for food preparation. The time it takes to estimate and record servings of food is a minor investment for the advantage an optimal diet will have on athletic performance.

Applications

It is clear that nutrition influences performance in a variety of sports, and swimming is no exception. Dietary deficiencies of iron, carbohydrates, and total calories have been shown to severely impact performance. Therefore, it is imperative that competitive swimmers know the basics of good nutrition, and have the ability to devise a healthy diet. All athletes should be aware by now that a healthy diet is not just something to be eaten the night before an event, but should be consumed all during training in order to optimize the quality of training.

Although many athletes may know that they should be meeting their energy needs and eating 65% of kilocalories as carbohydrates, 15% of kilocalories as protein and 20% of kilocalories as fat, it is believed that few are equipped to do so on their own. The results of the current study confirm this belief, and demonstrate that many Division IAA collegiate swimmers, particularly female swimmers, could benefit from some nutrition education and specific guidance for planning their diets.

Although the males in this study met their needs for energy and macronutrients on the average, several were undereating. This was improved by the use of the HEALTHY EATING guidebook. Females, on the other hand, appeared to be either chronically undereating or underreporting their food intake as they maintained their body weight despite eating less than calculated needs; it is also possible, however, that their calculated energy needs were overestimates of their true needs. Use of the guidebook, however, did improve their food intake.

The HEALTHY EATING guidebook was devised as a personalized tool for athletes to convert nutrition knowledge into practice. It is easy to use, practical, and teaches its users about nutrition as it is being used. Foods are grouped according to their macronutrient profiles; most commonly eaten foods including convenience and fast-foods are included in the guidebook. Users learn about food composition, and are less likely to view certain foods as "good" or "bad", but rather as protein-rich, carbohydrate-rich or low in fat. Each athlete has personalized daily food group goals, that is, a specified number of food group servings with a goal of meeting this number of servings each day to insure that a balanced diet rich in carbohydrates, moderate in protein, and low in fat is consumed. Users learn that they needn't avoid food high in fat or low in carbohydrate as long as these foods are consumed in moderation and fit into the overall HEALTHY EATING plan.

Swim coaches can optimize their athletes' performance by providing them with nutritional information and guidelines for eating an optimal diet. A coach needn't be a nutrition expert to impart this information; publications exist which specifically educate coaches about nutrition and provide guidelines for educating their athletes (8,9,18). Athletes will listen to their coaches advice—the coach is in a key position to optimize athletic performance not only through athletic training, but diet as well.

Acknowledgements

I gratefully acknowledge the cooperation and assistance of Coach Brenda Skelley, University of New Hampshire men's and women's swim coach, and Meghan McCarthy, captain of the women's swim team, as well as the diligent participation of the 15 UNH swimmers who made this study possible.

References

Device for Quantitative Measurements of Hydrodynamic Drag on Swimmers

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Abstract
A simple, versatile device for above-water and underwater towing of swimmers is described. This device may be used to study and to quantify the three dominant hydrodynamic drag forces on swimmers, namely frictional, form, and wave drag. It also may be used to train swimmers to optimize underwater movements at high speeds.

Keywords: sports physics, towing, swimming

Introduction
Hydrodynamic drag is a principal concern in swimming performance (1). The three principal drag types—frictional, form, and wave—arise from different physical mechanisms and contribute to or detract from athletic performance to varying degrees, depending on a number of variables. Frictional drag arises from the motion of water over a rough surface, e.g. a swim suit, hair, or skin. It scales linearly with the swimmer's velocity and, in general, it has a minor effect on swimming performance. Form drag arises from the motion of an object of physical extent through a fluid. The magnitude of the drag, \( F_r \), depends on the geometry of the object, the density of the fluid, \( \rho \), and the square of the object’s velocity. Mathematically, it may be expressed

\[
F_r = \frac{1}{2} \rho v^2 AC
\]

where \( F_r \) is the drag force, \( \rho \) is the density of water, \( v \) is the velocity of the swimmer, \( A \) is the cross-sectional area of the swimmer in the direction of travel, and \( C \) is an empirical constant (0.5 \( \leq C \leq 2 \)) that depends on the geometry of the swimmer. A streamlined swimmer will have a small \( C \) value. It should be noted that \( F_r \) scales as \( v^2 \), hence, becomes increasingly important at higher velocities.

The third, and perhaps most pernicious drag force, wave drag, arises when a swimmer creates surface waves, wakes, and turbulence. From the principle of conservation of energy, since surface waves carry energy, this energy must be supplied by an outside agent, namely the swimmer. The energy carried away by the waves is energy that might have been used more effectively to propel the swimmer to a faster time. Wave drag is potentially the most deleterious drag force since it scales as the cube of the swimmer's velocity. An effective way to reduce this force, of course, is to swim underwater. This tactic has been effectively employed by a number of swimmers, particularly during the starting phase of a race.

The importance of drag may be illustrated by imagining a swimmer pushing off the pool wall in the absence of any drag force; he could cruise forever at an undiminished speed. That swimmers must flail furiously just to maintain their speed is evidence that drag forces are quite important.

Drag, however, is not universally deleterious. For example, it has been established that form drag contributes to hydrodynamic lift and is actually critical to propulsion in many strokes. Further studies are needed to quantify and optimize the use of drag to improve swimming performances.

While drag has been the object of considerable interest by the swimming community, it has been difficult to perform quantifiable, controlled experiments isolating each of these drag terms. In this paper, we describe a simple, versatile device that will allow study of drag on swimmers under a variety of controlled experimental conditions, allowing independent variation of swimmer mass,
shape, velocity, orientation, surface roughness, and depth in water. In varying these independent variables, we hope to elucidate the origin of and possible cures for deleterious drag, and possibly identify and enhance beneficial drag. In addition, it may be possible to use this device to teach swimmers to minimize the effects of deleterious drag and to develop more powerful, efficient strokes.

Methods

In this section, we will discuss the construction, theory of operation, and possible applications of this device. In addition, initial results demonstrating the operation of the towing device will be presented.

The towing device is of simple construction (See Figure 1a). The framework consists of sturdy steel tubes (1.5" x 1.5" square, 1/8" walls). Mounted in this framework are a series of chains, sprockets, and pulleys which transmit a fixed towing force, \( F_t \), to the swimmer via a towing line in the water. The swimmer is pulled toward the towing device either above water or underwater, depending on how the device is configured. The towing force originates with the force exerted by falling weights. This gravitational force (weight) is \( W = mg \), where \( m \) is the mass of the falling weights, and \( g \) is the Earth’s gravitational acceleration, \( g = 9.81 \text{m/s}^2 \). The gravitational force is reduced in magnitude before it is applied to the swimmer as the towing force, \( F_t \), as shown in Figure 1b. This is accomplished by a pair of chain-linked, dual sprockets (A and B in Figure 1b).

Consider the chain/sprocket/weight combination used in this device (Figure 1b). Each of the dual sprockets, A and B, has a 3:1 ratio between the larger and smaller sprocket. Note that the subscripts on A and B will mirror the radii subscripts in Figure 1b, e.g. \( A_1 \) goes with radius \( r_1 \). The small sprocket, \( A_1 \) (radius \( r_1 = 3 \text{cm} \)) is attached to the falling weight, \( W \). The larger sprocket, \( A_2 \) (radius \( r_2 = 9 \text{cm} \)) is chain-linked to the smaller sprocket, \( B_1 \), and the larger sprocket, \( B_2 \), is chain-linked to sprocket \( C_1 \). Sprocket \( C_1 \) (radius \( r_3 = 3 \text{cm} \)) co-rotates with a spindle (\( r_3 = 3 \text{cm} \)) which has an independent reservoir of strong, thin line, which is threaded through two pulleys \( (P_1 \) and \( P_2 ) \) on the vertical shaft. The towing line from the spindle is ultimately linked to the swimmer. The vertical shaft, on which the pulleys are mounted, can be raised and lowered in the water to vary the depth at which a swimmer is towed.

If one assumes the falling weight has an instantaneous speed, \( v_0 \), then one can obtain the velocity with which the swimmer is pulled through the water. The velocity of the falling weight must equal the tangential velocity, \( v_r \), of sprocket \( A_1 \). Simply, it is \( v_r = r_1 \omega_1 \), where \( r_1 \) is its radius (m) and \( \omega_1 \) is its angular velocity (radians/sec.). \( A_1 \) and \( A_2 \) co-rotate on the same axle, hence they share the same \( \omega_1 \). This demands that the tangential velocity of \( A_2 \) is \( v_r(A_2) = r_2 \omega_1 \). Because of the direct chain-linking of the dual sprocket sets A and B, we have \( v_r(A_2) = r_2 \omega_1 \) and similarly to above, \( v_r(B_1) = r_3 \omega_1 \).

Applying similar analysis to sprocket \( C_1 \) and the final spindle, one obtains for the towing velocity of the swimmer:

\[
\nu_{\text{swimmer}} = \frac{r_1 f_1 r_2}{r_3 f_3} \nu_0 = K \nu_0
\]

For our device with \( \frac{f_1}{f_3} = 3 \) and \( \frac{r_1}{r_3} = 1.0 \), one obtains \( \nu_{\text{swimmer}} = 9 \nu_0 \), so that \( K = 9 \) for this device. The distance (and velocity) traveled by the swimmer is 9 times
that distance (and velocity) of the falling weights. Of course, one may adjust sprocket ratio, \( K \), by changing sprocket radii. For our device, the maximum falling distance for the weights is 1.5m, and therefore the swimmer can be towed a maximum of 13.5m, roughly half the length of a standard training pool.

The towing force on the swimmer, \( F_t \), is simply the gravitational force exerted by the falling weight, \( W = mg \), divided by the sprocket ratio, \( K \); that is:

\[
F_t = \frac{mg}{K} = \frac{r_s r_f m g}{r_s r_d}
\]

(3)

This can be derived from the principle of conservation of energy. For this device, \( F_t = \frac{mg}{g} \). Note that some of the weights’ gravitational potential energy will be incorporated in the rotational kinetic energy of spindles, chains, axles, and sprockets and that some will be dissipated by internal mechanical friction. These can be directly measured and accounted for in making drag measurements.

With this towing device, one may directly measure the drag force, \( F_d \), on the swimmer by noting that when the towed swimmer is in dynamic equilibrium, that is, when the swimmer is moving through the water at a constant velocity, then the magnitude of the towing force must equal the magnitude of the drag force, \( F_t = F_d \). This is a straightforward consequence of Newton’s Second Law. It is assumed here that the only forces acting on the swimmer in the horizontal direction are \( F_t \) and \( F_d \). Notice that when the swimmer is in dynamic equilibrium, the drag force, \( F_d \), can be established from the magnitude of the falling weights and the sprocket ratio, \( K \), through the relationship: \( F_d = F_t = \frac{mg}{K} \).

One of the primary goals for this device is to measure the magnitude of the various drag forces versus the swimmers' velocity. The device is designed such that it is unnecessary to monitor independently the velocity of the swimmer to determine when dynamic equilibrium (i.e. \( F_t = F_d \)) has been achieved; it suffices to monitor the velocity of the falling weight. This is done conveniently by monitoring the angular velocity of sprocket A in Figure 1b. The rotation of sprocket A is measured via the voltage drop across a 10-turn potentiometer which is directly coupled to A's axle. The electronic circuit for the towing device is shown in Figure 2. As the weights fall, sprocket A turns, which varies the voltage drop across the potentiometer. Thus, since the speed of the swimmer is directly proportional to the speed of the falling weights (Eq. 2), and the falling weight is monitored by the potentiometer, one has direct electronic information about the swimmer’s speed.

Experimentally, when the weight is released, the x coordinate of the x-y recorder is triggered and swept by a linearly increasing ramp voltage from the signal generator; this acts as a time base for the measurement. As the weights fall and tow the swimmer, sprocket A turns, thereby changing the voltage across the potentiometer. This voltage signal is fed into the x-y recorder as they coordinate. The resultant trace depicts the voltage output of the potentiometer versus time. Since voltage is directly proportional to the swimmer’s location in the pool, that is, to distance, voltage and distance may be used interchangeably. In Figure 3, two position versus time traces are presented which are qualitatively similar to experimental plots obtained in initial tests of this device. Region I of curve B corresponds to the period of acceleration for the swimmer, region II to the period of dynamic equilibrium, and region III to where the weight reaches the ground and the swimmer decelerates to rest.

The first and second time derivatives of these curves are proportional to the swimmer’s velocity and acceleration during the towing periods. Although regions I and II probably contain interesting physics, we are concerned primarily with region II. The slope of region II is proportional to the swimmer’s velocity when dynamic
equilibrium has been reached between the towing force, $F_t$, and the various drag forces, $F_d$. In Figure 3, for instance, the slope of curve A is steeper than curve B, indicating that the velocity of the swimmer during trial A was greater than in trial B.

**Results**

Initial tests of the towing device were carried out at the University of San Diego swimming pool, a 25 meter competition size facility. The purpose of these tests was to demonstrate the operation of the device, not to make detailed studies of drag. These will be taken up in future experiments.

The test subject was a 1.6m, 50 kg female. Water temperature was 301-302 K. The subject lay face-down and was towed across the surface of the water with her arms reaching out ahead of her. Figure 4 presents voltage (distance) versus time plots for the subject under two different towing forces. For curve C, the subject was towed by 22 Newtons of force while for curve D, 44 Newtons of force. These correspond to 20 kg and 40 kg of falling weights, respectively. These curves qualitatively resemble the idealized curves A and B from Figure 3, displaying acceleration, dynamic equilibrium, and deceleration phases. The humps in curves C and D during the acceleration phase are believed to be due to the swimmer rising out of the water in response to the towing force and assuming a new stable equilibrium position.

The dynamic equilibrium sections of curves C and D render horizontal velocities for the subject of 0.86 m/s and 1.3 m/s respectively. The regions of dynamic equilibria show a high degree of linearity such that accurate measurements of drag forces should be attainable.

In the initial tests, the subject attained a velocity of 1.3 m/s under 44 Newtons of towing force. In order to mimic competitive swimming speeds, one must apply considerably greater force. A realistic estimate of the maximum towing velocity that can be achieved with this device can be obtained by equating the maximum achievable towing force to the drag force. The towing device is structurally able to bear over 600 kg of weights, thus should be able to apply over 660 N of towing force to the swimmer. Consider towing underwater an ellipsoidal object of comparable dimensions to a swimmer (length = 2m, maximum cross-sectional area = $\pi r^2 = \pi (1.5 \times 10^{-2}m)^2$) If one assumes the largest drag term is form drag, then in dynamic equilibrium, one may equate the maximum achievable towing force to the form drag, Equation (1). Isolating velocity, one obtains,

$$v_{max} = \left(\frac{2F_d}{\rho AC}\right)^{1/2}$$

(4)

If one sets $C = 1$, $\rho = 10^3 kg/m^3$, and $F_t = F_d = 660N$, then one calculates $v_{max} = 4.5 m/sec$, a velocity greater than that achieved by the fastest swimmers. While a simple change of sprocket ratios, this $v_{max}$ can be doubled easily, but at the expense of reducing towing distance.

**Application**

Typically, all three forms of drag operate simultaneously on a swimmer. The effect of each drag term, however, may be isolated and studied by appropriate application of this device. Assume extraneous experimental parameters have been fixed, such as the swimmer's mass, body type, water temperature, viscosity, and so forth. Then one may isolate the frictional drag term first by fixing the towing depth, the body orientation of the swimmer, and the magnitude of the falling weight, and then by varying the clothing and/or surface characteristics of the swimmer. By examining the slope of the x-y trace for each trial, one can determine quantitatively the swimmer's velocity as a function of his surface characteristics at a fixed $F_t$. From this, one can infer which surface characteristics are best for one's application. One may also vary the magnitude of the falling weights, hence, the towing velocity, and thereby study the velocity dependence of frictional drag for different surfaces. One particular question we hope to address is: Does shaving one's body before competition significantly decrease frictional drag (2)?

Form drag may be isolated by fixing the above-mentioned experimental parameters and then simply changing the swimmer's body orientation. For example, one might compare the absolute drag of a swimmer in a streamline prone position versus a tucked, balled position. One might also examine how form drag varies with velocity by holding position constant, then varying velocity by varying the weight on the towing device which controls the towing force. In order to avoid accidentally introducing surface effects, particularly wave drag, these experiments might be done best at a meter or two below the surface.

Wave drag can be studied by fixing the swimmer's body

![Graph](image-url)
orientation and then towing at different depths. For example, one might tow first at a depth of 3m, where surface waves and wakes are not generated. On subsequent trials, one could tow closer and closer to the surface. In monitoring the swimmer's velocity as a function of depth, one can infer the magnitude of the wave drag which also should be a function of depth. From such studies, one may discover whether there is an optimum depth at which to swim.

It is hoped that future, detailed studies with this towing device will allow better understanding of each of the drag terms. A number of other studies are readily suggested based on the broad parameter range of this sport.

In addition to aiding the study of drag forces, this device may be useful in teaching swimmers better swimming technique. For example, in the underwater launch or push-off phase of a race, an athlete wishes to minimize form drag. By towing a swimmer at competitive velocities underwater, the swimmer may experiment with different body orientations, receive immediate quantitative feedback as to the efficiency of those positions, and thus learn to reduce his form drag. Or, perhaps, one may wish to use this device in overspeed training for swimmers in a manner analogous to that of track and field sprints. In track, it has been shown effective to physically tow sprinters at velocities higher than at which they normally run. In doing so, a sprinter can become acclimated to new, higher velocities. Perhaps a similar technique can be applied to swimming by towing swimmers with this device at velocities slightly higher than they normally achieve, thereby acclimating them to more powerful, more efficient strokes.

Acknowledgements

It is our pleasure to acknowledge the assistance and advice of Mr. Gary Becker of USD, and funding by USD Associated Student Grants.

References

### 1993 WSCA Gold Medal Clinic

Join the World Swimming Coaches Association in beautiful Honolulu, Hawaii, May 17-22, 1993 for the WSCA Gold Medal Clinic. Join the World's Great Coaches for a week of education! Invited Speakers include:

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### Schedule

**Monday, May 17th**
- **9am-12pm** Registration & Welcome Lounges Open.
- **2-5:30pm** General Sessions
  - Talk 1 - 2-3:30pm
  - Talk 2 - 4-5:30pm
- **5:30-7pm** Social Activity
- **7-10pm** Group Discussions or free to explore island.

**Tuesday, May 18th**
- **8am-12pm** General Sessions
  - Talk 3 - 8-9:30am
  - Coffee Break: 9:30-10am
  - Talk 4 - 10-11:30am
- **12-1pm** Lunch available in Exhibit Hall
- **1-6pm** Group Discussions or free to explore island.

**Wednesday, May 19th**
- **8-11:30am** General Sessions
  - Talk 5 - 8-9:30am
  - Coffee Break: 9:30-10am
  - Talk 6 - 10-11:30am
- **11:30-12:30** Panel Discussion with presentations 1-6.
- **12:30-1:30** Lunch available in Exhibit Hall
- **1:30-6pm** Group Discussions or free to explore island.
- **7-8:30pm** "Ideas that Work"
  1. Motivating Swimmers in Training
  2. Pre & Post race talks with coaches
  3. How to split various races.

**Thursday, May 20th**
- **8-11:30am** General Sessions
- **12:30-1:30** Lunch available in Exhibit Hall
- **1:30-6pm** Group Discussions or free to explore island.
- **7-9pm** Panel Discussion: Topic to be announced.

**Friday, May 21st**
- **8am-12pm** General Sessions
  - Talk 9 - 8-9am
  - Talk 10 - 9:30-10:30am
  - Talk 11 - 11am-12pm
- **12-6pm** Group Discussions or free to explore island.
- **6-7pm** Open Bar prior to WSCA Awards Banquet
- **7-9pm** WSCA Awards Banquet "Coach of the Quadrennium" to be announced.

**Saturday, May 22nd**
- **8-11am** Discussion Groups
  - (Coffee Break at 9:30)
  - 5 Topics to be announced
- **11am-1pm** Lunch Break
- **1-4pm** WSCA Board Meeting
THE JOURNAL OF SWIMMING RESEARCH

—AUTHOR GUIDELINES—
(Revised May, 1990)

The JOURNAL OF SWIMMING RESEARCH is an official publication of the American Swimming Coaches Association. Manuscripts dealing with original investigations, comprehensive reviews, or brief reviews on the science of swimming and closely related topics, will be considered for publication. This journal is a researcher-to-coach publication. Information presented in the manuscript must be receiver-oriented. Authors submitting manuscripts to this journal must verify in writing that its contents represent original unpublished material that is not under consideration for publication elsewhere.

EDITORIAL STYLE. The author should submit three copies of a manuscript, typewritten and double-spaced with 1.5" margins on all edges. A short running title should be repeated at the top right corner of each page followed directly below by the page number. Authors should avoid all information which will identify human subjects. English will be the language of this publication. As a general rule, only standardized abbreviations and symbols should be used. The first time an uncommon abbreviation appears it should be preceded by the full word or name it represents. The author is encouraged to refer to the Publication Manual of the American Psychological Association, 3rd edition, for editorial style concerning punctuation and abbreviations, construction of tables and figures, presentation of statistical symbols or mathematical equations, and use of standard units of measurement.

Manuscripts should contain the following elements placed in the following order:

1. TITLE PAGE. The title page should include the manuscript title, names of author(s) and their academic degree(s), name(s) and institution(s) where work was performed, an address and telephone number for editorial correspondence concerning the manuscript.

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

3. INDEX TERMS. A list of three or more words or short phrases not included in the title should be appended to the abstract.

4. 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. Non-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 the data presented in the findings section.
   e. Applications. The author should provide conclusions and possible applications suggested by their data. This section of the manuscript is of particular importance to the mission of the journal. It should be at least 500 words in length and provide in simple, laymen terms, an interpretation of the findings and implications to the on-deck coaching and training of swimmers. Where appropriate, examples of how the findings may be applied and/or how the findings may lead to further research questions are encouraged.

4. REFERENCES. The list of references should not exceed 20. They should be listed alphabetically by the last name of the author and typed double-spaced. The notation of the references in the body of the paper should be numbered in parentheses, one reference to a number. Journal articles should contain the last name of the first author, followed by initials, initials and last names of each co-author, title of article (first word only capitalized), name of journal (as abbreviated in the INDEX MEDICUS published by the Library of Congress), volume, inclusive pages, and year. An example would be: Karlsson, J., L. Nordebo, L. Jorfeldt and B. Saltin. Muscle isostatic, ATP and CP levels during exercise and after physical training in man. J. Appl. Physiol. 33:199-203, 1972.

5. TABLES AND FIGURES. Each table must be typed double-spaced on a separate sheet and numbered consecutively, beginning with Table 1, and have a title or caption. Tables should not duplicate information in the text or in figures. Figures should be sharp, unmounted glossy photographic prints not larger than 8.5 x 11 inches. They should be numbered consecutively with Arabic numerals. Each figure must have a legend; they shall be grouped in numerical order and typed double-spaced on a separate sheet.

BRIEF REVIEWS. Authors are encouraged to submit manuscripts suitable for Brief Review papers that can be used for educating the non-expert on a particular issue or problem. Brief reviews will also be solicited by the editor or editorial board, however, solicitation is not guaranteed for acceptance.

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