THE JOURNAL OF SWIMMING RESEARCH

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Editor’s Preview

The first paper in this issue by Kame, et al presents the results of a study in which a collegiate swimming team was trained using high intensity, short duration swims at speeds faster than racepace. In addition to defining the effects on aerobic power, stroking characteristics, and efficiency, the authors also compared the improvements in competitive performance with the prior season in which more traditional forms of training were employed. Despite training only once per day with a total volume of about 3,000 yds/day, the swimmers experienced a 20% increase in aerobic power. Whether this improvement is greater than in the prior season was not tested and would be an interesting study for future research. Perhaps the most provocative finding of this study was that the improvements in competitive performance were significantly greater than in the prior season, supporting the notion that training should be as specific as possible to the energetic and mechanical demands of the races for which the swimmers are training.

The paper by Miserochi, et al shows a possible application of a mathematical model of swimming that was originally developed for track athletes. Of primary interest here is the finding that over several consecutive seasons, improvements in competitive performance seem to be proportional for all distances of a particular stroke. In other words, if one were to graph a swimmer’s velocity for each stroke event against the distance, the slope of this line does not seem to change over several years. It would be useful to know, however, if this slope can be altered differently by using different forms of training such as high intensity training vs. long, slow training. The authors also suggest that the mathematical model can be used to determine at what distance the swimmer has the best chance for success. However, the specifics of how this would be accomplished are not detailed. Judging by the data in Figure 6, it looks like if the slope of the velocity/distance plot is -0.4 the predicted best distance is 400 m, if slope is -0.6 the best distance is 200 m, and if slope is -0.8 the best distance is 100 m. For coaches and researchers who wish to use mathematical modelling as a tool for understanding our sport, this approach seems to offer a reasonable start.

The third paper in this issue (Rohrs, et al) describes a study which attempted to determine which of several field tests of anaerobic power relates best to freestyle swimming performance. The authors describe several tests which are categorized as either general tests or specific tests. Of the general tests, the one used most often by coaches is the vertical jump test. This test did not significantly correlate with 25 yd performance for males but did correlate significantly (even though the correlation was low) with 50 and 100 yd performance. In the female swimmers, the vertical jump test did not correlate significantly with any of the swim performances. Of the specific tests, the power test on the Biokinetic bench was best for the males while the tethered swim test was best for the females (this correlation was also very low).

Rick Sharp

Guest Reviewers—1990

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Physiologic Responses to High Intensity Training in Competitive University Swimmers

VINCENT D. KAME, JR. MS, ATC
Research Assistant Department of Physiology
State University of New York at Buffalo

DAVID R. PENDERGAST EdD
Professor of Physiology
State University of New York at Buffalo

BUDD TERNIN MA
Men’s Swimming and Diving Coach
State University of New York at Buffalo

Abstract
A season long high intensity training program was performed by 17 male competitive collegiate swimmers. Data collected for the study were maximal and submaximal oxygen consumption (\(\dot{V}O_2\)) and assessment of stroke frequency (\(S\)) vs. velocity (\(v\)). Each subject was tested pre-season, mid-season and post-season while performing the front crawl. \(\dot{V}O_2\) was determined during a tethered swim to exhaustion, while \(S\) and \(v\) were taken during successive free swims of one length of a 22 meter pool. The training program was individually based and focused on swimming at or near maximum \(v\) and the corresponding \(S\) for relatively short distances. There were significant (p≤0.05) increases in \(\dot{V}O_2\) peak, \(S_{\text{max}}\) and \(v_{\text{max}}\) when post-season was compared to pre-season. The implications of the work are to alter training programs toward increased intensity quality rather than low intensity quantity training for optimal in-season improvement.

Introduction
In swimming, performance is limited by the metabolic capability as well as the skill of the athlete. Craig and Pendergast (3) showed that velocity is a product of stroke frequency and distance per stroke, with velocity increasing with an increasing stroke frequency and a decreasing distance per stroke. In addition, it has been shown that the distance traveled per stroke correlated with actual swimming performance (2). Maximum velocity has also been related to metabolic capability of the athlete (4). The present study was designed to test a new type of training program which focused on training the athlete at high stroke frequency, velocity and level of metabolic demand. It was hoped this would bring about maximum benefits and improvements in the variables which limit performance.

Methods
The subjects for this study were college age males (\(n = 17\)) who were members of a University Division II swimming team whose characteristics are presented in table 1. Each underwent a pre-season physical exam according to the university’s guidelines. The subjects competed in one of the four primary strokes, however, all participated in at least one free style event, and therefore the front crawl was used for all tests. Each subject was tested for all parameters before, at the mid-point and after a full season of training and competition. Pre-season testing was performed during the initial period of training over a two week span, mid-season testing was performed after an invitational competition and

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before a month long break before any further competition, and post-season testing was performed immediately after the season was complete during a similar two week period.

Data collected were maximal and submaximal oxygen consumption (\(\overline{VO}_2\)), and stroke frequency (\(\ddot{S}\)) vs. velocity (\(v\)) relationships. Oxygen consumption was determined using the open circuit spirometry method during tethered swimming until exhaustion. Workloads were increased every two minutes in either 1kg or 0.5kg increments (see table 2).

In order to measure the relationship between stroke frequency and velocity (1) each subject was instructed to push off a wall of a 22 m pool and swim one length maintaining constant velocity with a very slow arm rate. The subject was then instructed to increase \(\ddot{S}\) during subsequent trials until the subject was swimming at what they perceived was their maximum velocity. It was then necessary to instruct the subject to perform at higher \(\ddot{S}\) than what they associated with maximal \(v\) in order to ensure that a true maximal \(v\) was established. On each trial the subject was timed during a 10 m portion of the swim so that \(v\) could be determined.

In order to determine the effects of a season utilizing this type of training \(\overline{VO}_2\) peak, \(\dddot{S}\) max and \(v\) max were compared pre-season vs. post-season using a Students t-test with the results being considered significant if \(p \leq .05\). In addition to this the slopes of the linear portions of the \(\overline{VO}_2\) vs. Tethered Drag as well as the \(\ddot{S}\) vs. \(v\) graphs were analyzed to determine the training effect on the efficiency of the swimming. The latter results were also be considered significant at the \(p \leq .05\) level.

The training method employed concentrated on high intensity quality work over relatively short total distances. Traditionally a swimming workout consisted of 8-12 thousand meters of work at considerable lower intensities than the athlete would utilize during competition (5,7). This method, however, was designed to train the swimmer at or above the muscular and metabolic intensity the competition would demand. For each practice a goal \(v\) and corresponding \(\ddot{S}\) was identified for each swimmer and this was monitored for each swimmer. This goal \(v\) and \(\ddot{S}\) was at an higher than standard intensity and one which corresponded to near peak \(v\). The determination of \(\ddot{S}\) and \(v\) were important aspects of the training program because it allowed for specific monitoring of the swimmer's training intensity and quality of work. The mid-season testing was used to alter the training based on improvements during the first half of the season. A typical workout consisted of a 1 hour period of high intensity work broken up into bouts which were somewhat shorter than the actual event itself for a given swimmer. A schedule of two consecutive days intensity work followed by two days light work was employed to allow for maximal glycogen depletion and replenishment between sets of high intensity workouts. The pattern of exercise and rest was utilized to avoid chronic fatigue and the resultant decline in training performance.

The competitive effects of the high intensity training were evaluated by comparing the improvement in swimming times during competition for distances of 50, 100, 200, 500, 1000 and 1650 yards between the season utilizing high intensity training and the previous season where lower intensity and longer duration training was used. The lower intensity training consisted of two workouts per day with a total distance of 10-12,000 yards made up of 10 x 100 yards on one minute 15 seconds and long sets of 200 yards with short rest periods for sprinters. The training for distance swimmers consisted of 2 x 2000 yards or 10 x 500 yards with short rest periods. The specifics of the high intensity training included dividing the race distances into thirds and having the swimmer complete these at race pace with 45 seconds rest between each trial. Once the swimmer failed to maintain race intensity for a trial, he was given 90 seconds rest and then resumed training. When the athlete could achieve 10-15 repeats at race intensity, the rest interval was decreased by 5 seconds until the race could be completed at the selected goal time. Once this was accomplished a new and faster goal was selected and the process was repeated. The swimmers trained once daily for 1 hour covering a distance of approximately 3,000 yards. A cycle of two consecutive days of intensity work and two rest days with technique work was used for reasons stated above.

Results

There was a statistically significant increase (\(t = -5.87, p = 0.000\)) in peak oxygen consumption (\(\overline{VO}_2\)) from \(3.12 \pm 0.11\) to \(3.91 \pm 0.01\) L/min pre-season vs. post-season. This 20 percent increase was accomplished without a change in the relationship between \(\overline{VO}_2\) and workload, as determined by the similarity in the slopes of the \(\overline{VO}_2\) vs. tethered drag pre-season vs. post-season (Figure 1).

Maximum velocity, determined during the stroke frequency analysis, increased from \(1.62 \pm 0.01\) m/sec pre-
season to 1.78 ± 0.02 m/sec post-season. This increase was statistically significant (t = -6.01, p = 0.000) and was due to a significant increase in the maximal stroke frequency (t = -4.45, p = 0.001) without a reduction in v. The distance traveled per stroke between the two points in training was not altered (see table 3, Figure 2) as described by the slope of the linear portion of the S vs. v graph.

The competitive swimming times for free style between 50 and 1650 yards for the experimental and the previous season, which was used as a control, were compared to evaluate performance changes. The improvements in times for 50 to 1650 yards were significantly greater during the experimental than the control season. Improvements ranged from 0.86 to 34.9 seconds (2.6 ± 0.5%) and 0.38 to 21.85 seconds (2.2 ± 0.7%) for the two seasons respectively.

**Discussion**

Exercise training causes changes in the body’s ability to deliver blood and oxygen to the working musculature and allows for increases in the amount of work performed. It has been shown that endurance training increases cardiac output via an increase in stroke volume as maximal heart rate is decreased (14). Peripheral adaptations include an increase in the muscle’s oxidative as well as anaerobic capacity. Peripherally there is an increase in oxidative capacity which results in better extraction of oxygen from the blood delivered as well as an increase in the regional blood flow (6, 11, 14).

Numerous studies have shown that increases in swimming capabilities can only be facilitated via a program of swim training (8, 11, 12). These studies have consistently demonstrated that increases in \( \dot{V}O_2 \) max resulting from other forms of exercise training are not reflected when the subjects were tested swimming. Because swimming has shown such a high degree of specificity to training, this training program was designed to condition the athlete to the specific intensities that competition would demand rather than simply specific to swimming.

Mean peak pre-season \( \dot{V}O_2 \) was within the range associated with recreational swimmers (11, 12). The post-season value (3.91 ± 0.01) was slightly lower than Magel and Faulkner obtained during tethered swimming with college swimmers. This can be explained due to the fact that the above study was performed on Division I athletes. Among these were 7 All-Americans and 2 Olympians (10). The metabolic increases observed during this study were greater than those reported by others using a more traditional method. Neufer et al. (13) reported a 14.3 percent increase in \( \dot{V}O_2 \) over an entire season of training at approximately 9,000 meters per day. In addition to this, Costill et al. (1) and Kirwan et al. (9) showed no improvement in either physiologic tests or swimming performance when the training distance was doubled and intensity kept constant.

Although there were increases in \( \dot{V}O_2 \) peak, this was not reflected in any increases in the swimming efficiency of the subjects. If efficiency increased, one would ex-
pect a decrease slope of the \( \dot{V}O_2 \) vs. tethered drag line after training that would represent an increased ability to swim more efficiently at any given workload. However, in this study there was no decrease in the slope even though \( \dot{V}O_2 \) peak increased significantly (see figure 1).

The stroke frequency and velocity data (Table 3) agree well with that generated by Craig and Pendergast (3). The data suggest that the increase in \( \dot{V}O_2 \) allowed for maintenance of stroke mechanics at higher \( S \), which resulted in an increased \( v \) (see figure 2). Velocity could have also been increased by an increase in the skill level of the athlete. If there was an increase in the distance per stroke, the athlete could attain a higher \( v \) at any given \( S \). This does not appear to be the case in this study due to the similarity of the slopes of the linear portion of the \( S \) vs. \( v \) graph pre and post training (Figure 2).

The physiologic improvements made during this type of training, specifically the increased \( \dot{V}O_2 \) peak as well as \( v \) max, were reflected in the performance of the athletes during competition. This can be observed by the significant increase in time improvements during the experimental season when compared to a season where a lower intensity type training was used.

Conclusion

The unique aspect of high intensity training is the use of shorter distances and higher velocities during the workouts than are typically associated with the standard program. The daily sets consisted of swimming at a prescribed pace for each individual which was at optimal race velocity determined from the relationship between stroke frequency and velocity. The distance per set, rest interval between sets and the training intensity are the parameters regulated during the workouts. As the athlete's physical condition and/or technical ability improves he will be able to sustain his velocity and stroke frequency at proper levels for a longer period of time and require shorter rest intervals before he can resume swimming at the desired intensity.

During the workout the coach monitors the velocity and stroke frequency of each swimmer periodically. Velocity can be easily recorded by using the split time, and stroke frequency can be determined by timing a selected number of strokes. It is important that the athlete maintain the optimal position on his individual stroke frequency vs. velocity relationship for maximal benefits. A program of this type is very individualized and the athlete must bear some responsibility for improvement by maintaining the proper intensity during the workout.

This program succeeded in increasing \( \dot{V}O_2 \) peak, \( S \) and \( v \) maximum, resulting in improved performance. It did not, however, result in improved skill. The present program was designed to be an in-season program employed to increase metabolic factors which limit performance, and specifically did not address skill. An out of season program focusing on reducing stroke rate for a given velocity is being employed in order to increase efficiency and distance per stroke. The data suggest that high intensity training brings about optimal changes in physiologic parameters, but other factors, such as skill of the athlete must be addressed to facilitate maximal performance.

References


Acknowledgements

Gratitude is extended to Don Wilson, Mary Lou Wilson and to Jeanne Catalano for their support of this study. This project was partially funded by a grant from the office of US Navy # 1506738A. Special thanks is extended to the athletes who participated in the study.
Mathematical Modelling of Competitive Swimming

GIUSEPPE Miserocchi, M.D.
Professor of Physiology
FRANCESCO Confalonieri, M.D.
MARCO Lorenzi, M.Sc.

Instituto di Fisiologia Umana, Universita’ degli Studi,
Milano and Centro di Medicina Sportiva MEDISPOR.

Abstract

We have modelled the individual maximum velocity ($V_{\text{max}}$) vs race distance (RD) relationships in elite swimmers engaged in the four Olympic styles (free style: $N = 34$; butterfly: $N = 12$; backstroke: $N = 10$; breaststroke: $N = 12$). $V_{\text{max}}$ data were derived from the best performances obtained by each athlete on various distances up to 4 years of career. The following model was used: $V_{\text{max}} = a \cdot \log RD + b$. Coefficient $a$ varied among subjects and for different styles but within each athlete remained constant over the years. Actual improvements in performance were modelled for any single athlete by increase in coefficient $b$. This increase varied among subjects averaging 5% of initial value in 4 years. Coefficient $a$ could be related to the specific endowment of a swimmer for a given race distance, defined as Best Race Distance (BRD). The latter was established by rating the individual performances on various race distances with the FIN Table. The present study is proposed as a tool to model the training program of a swimmer as it allows to early define the race distance best suited to any single athlete and the reasonable athletic targets over several years of competitive swimming.

Competitive swimming requires that a given distance is covered in the shortest time, namely at the maximum speed by each athlete. As in other sports where this aim has to be achieved, one is facing a peculiar feature of the biological engine, that is a decrease in maximum speed, and thus in total power output, as the length of the race increases (9, 10). This reflects the phenomenon of fatigue that in turn, is related to the interaction of the exergonic aerobic and anaerobic mechanisms (1, 16, 17). Such interaction is expected to differ among subjects due to the various contribution of the two mechanisms related to individual cardiovascular, muscular and enzymatic biotypological differences (2, 4, 8, 13).

A modelling of the decrease in total power output with increasing race distance has stimulated several investigators (3, 14), although a few attempts were made trying to relate this feature of the biological engine to the individual characteristics (8). Recently, an attempt has been done to model the individual decrease in total power output for track and field events from 800m up to the marathon based on the decrease in the maximum speed attained by each athlete ($V_{\text{max}}$) on the various race distances (RD) (11, 15). The $V_{\text{max}}$ vs race distance relationship becomes linear in a semilog plot, namely by considering an equation of the type: $V_{\text{max}} = a \cdot \log RD + b$. Coefficient $a$ represents the slope of the relationship: in other words the loss in $V_{\text{max}}$ per unit increase in log of race distance. Coefficient $a$ has a negative sign, the greater its modulus the greater the loss in $V_{\text{max}}$ per unit increase in race distance. When distance and time are expressed in km and hours respectively, coefficient $b$ corresponds to the $V_{\text{max}}$ for a race distance equal to 1km. Using this mathematical modelling it was possible to relate the coefficients $a$ and $b$ to the specific endowment to a given race distance and the athletic strength respectively. Since this modelling proved useful for individual training programs, our present aim was that of developing a similar analysis for competitive swimming.

Methods

The study was performed on 68 male athletes engaged in the various styles (12 butterfly, 10 backstroke, 12 breaststroke, 34 freestyle) followed up to 4 years. The first year considered corresponded to the one where each athlete's performance on the olympic race distances for each style was included in the first 80 of the italian rank-
ing. The age corresponding to the first year ranged 15-17 years. The data considered in this study were the best performances attained by any athlete in each subsequent year. For the mathematical treatment of the data we needed the performances on at least three race distances and since for styles other than freestyle only two race distances (100 and 200m) are included in the Olympic program, we added the best performances on the 50m. These data could be easily gathered through a collaboration with the coaches as this race distance is commonly included in the training programs. In summary, for freestyle we considered the performances on 50, 100, 200, 400, 1500m and for other styles the performances on 50, 100 and 200m.

Analysis of the Data

For simplicity of mathematical handling we used the semilog mathematical model to regress the velocities relative to the actual performances vs the corresponding race distances. Namely, in analogy with what previously done (11, 15) we used the following model: \( V_{\text{max}}(\text{RD}) = a \log \text{RD} + b \). For each athlete we found the regression relative to each year considered. We also found for each athlete the distance corresponding to its best performance (defined as Best Race Distance, BRD) according to the FIN table. This table, conventionally used by coaches, was developed in the early eighties with the scope to allow a relative comparison of performances on various race distances, in analogy with what had been previously done for track and field events. Although different versions of such table exist, the common logic is to attribute points to any performance on any distance and for the different specialties: the better the performance the higher is the score. For example for a swimmer whose best timing on 100, 200 and 400m free style was: 50s 20”, 1m 51s 24” and 3m 55s 84”, the corresponding points based on FIN table are: 1000, 980 and 965; accordingly, the best relative performance is on the 100m race. Based on this analysis we ranked this athlete in the 100m BRD group. Following this approach, we grouped the swimmers in the various styles relative to their BRD. For each BRD group we then calculated the average value of coefficient \( a \).

Findings

Fig. 1 presents the semilog regressions relative to the first year performances for subjects engaged in the four different styles. It can be seen that the semilog model

---

**Figure 1.**

Individual \( V_{\text{max}} \) vs race distance relationships in four swimmers engaged in different styles.
describes satisfactorily the data as shown by the high r² value. In fact in all the regressions considered we always found r² > 0.97. In these regressions coefficient a reflects the decrease in Vmax with increase in RD (on semilog paper) and thus it is a good index of the decrease in power output of the biological engine for unit increase in race distance.

It may be argued that coefficient a is differently influenced by distances considered due to the start dive and the total number of turns. In the attempt to evaluate how these factors might affect our mathematical model, we recalculated the individual Vmax vs logRD regressions after decreasing the actual velocities by a factor that would quantitate the specific advantage due to dive and turns (7). Fig. 2 shows, as an example, this analysis performed for a free style swimmer: it can be seen that the experimental regression based on actual performances (open symbols) remains essentially unchanged after the correction of the original data considering the dive and turn advantage factor (closed symbols).

Fig. 3 shows how coefficient a was modified in subsequent years of competitive activity. This study was performed in a population of 20 free style swimmers followed for at least two years. The value of coefficient a corresponding to the first year ranged in this group from 0.13 to 0.9. Clearly the data indicate that, in any given athlete, no substantial changes in coefficient a was observed so that it can be considered constant.

Fig. 4 shows, as a representative example, the Vmax vs logRD regressions obtained for 4 subsequent years in a freestyle swimmer belonging to the group followed for several years. The figure shows that the improvements in performance on any single race distance may be modelled by regressions being progressively displaced upward in an almost parallel fashion. In other words, the improvements can be modelled by a progressive increase in coefficient b with no change in coefficient a (as already shown by Fig. 3). We may recall that coefficient b has the dimension of velocity and, according to the mathematical model used, represents Vmax over a 1km race distance.

The rate of increase in coefficient b was variable in the 20 freestyle swimmers we studied and its average percent increase relative to its first year value is shown in Fig. 5.

Relation between coefficient a and BRD

Since coefficient a describes the decrease in power output of the biological engine and since the latter relates to a specific endowment to a more race distance, namely Best Race Distance (BRD), we propose a relationship, within each athlete, between coefficient a and BRD. Within each style we then averaged the coefficient a of swimmers having the same BRD. Fig. 6 presents the regressions between BRD and the average values of coefficient a in the four styles considered.
Discussion

The maximal speed is defined (6) as:

\[ V_{\text{max}} = \frac{E_{\text{max}}}{C} \]

If one considers \( E_{\text{max}} \) as resulting from anaerobic and aerobic energy yield, the equation may be rewritten as:

\[ V_{\text{max}} = \frac{(F \cdot E_{\text{max}}^{\text{AN}} + F' \cdot E_{\text{max}}^{\text{A}})}{C} \]

where \( E_{\text{max}}^{\text{AN}} \) and \( E_{\text{max}}^{\text{A}} \) are the maximum anaerobic and aerobic power output and \( F \) and \( F' \) are the fractions of these power being used, \( C \) representing the energy cost per unit distance covered. The decrease in \( V_{\text{max}} \) with increasing distance reflects the reduction of the ratio appearing on the right-hand side of the equation. Most of this reduction is due to a decrease in \( F \cdot E_{\text{max}}^{\text{AN}} \) which is not offset by an equal increase in \( F' \cdot E_{\text{max}}^{\text{A}} \). Clearly, the contributions of the two mechanisms relate to biotypological features. Furthermore, for a given speed, one may expect differences in the anaerobic/aerobic contribution as a function of the style and technical ability. One should also recall that the efficiency is usually increasing with increasing speed (5, 9).

Figure 5.
Average percent increase in coefficient b (relative to its first year value) up to 4 years of competitive swimming.

Figure 6.
Best Race Distance (BRD) vs coefficient a regressions for swimmers belonging to the four style groups. The values of coefficient a reported for each BRD represent the mean value for athletes having the same BRD.
Using the simple mathematical model that we propose, the decrease in total power output is simply described by coefficient $a$. The values of $a$ encountered in the population of swimmers studied are generally small in absolute term, particularly if they are compared to those found in track and field running (11, 15). In fact the values of $a$ in swimmers reflect the difficulty to develop high maximum velocities on shorter distance due to the much higher drag in water compared to air locomotion (9, 12). We can also note that, for BRD ranging from 50 to 200m (Fig. 6), the average $a$ values differ in the four styles. For 200m BRD swimmers, the $a$ value is greater in butterfly compared to other styles, likely reflecting a greater decrease in efficiency with decreasing speed in the butterfly compared to other styles. One can further comment that the high value of $a$ found for 50m BRD freestyle swimmers likely reflects a homogeneous group of sprint runners.

It is of interest to note that coefficient $a$ appears very stable. In as much as coefficient $a$ can be correlated to BRD, it can be considered as a good and early index of the specific endowment of a swimmer to a given race distance. This conclusion applies so far to the late teens group studied and cannot be promptly extended to the age group athletes. To describe how a young swimmer’s physiological endowment to a given race event is developing with age requires a similar study to be done on the age group swimmers.

Our analysis also suggests that improvement in performance can be modelled by increase in coefficient $b$. Although the increase in $b$ appears variable to some extent, we believe that the present analysis may allow to tabulate at least a set of reasonable performances that may considered within reach for each athlete.

Conclusions

This study proposes an analysis simply based on actual performances, thus on clock timing. The originality of the idea implies that the data base for each athlete reflects the interaction of different variables including the exergonic processes, technical ability and psychological characteristics. The analysis implies a little knowledge of statistics and can be handled with a table calculator. It can actually be done by developing a simple software. Its use provides to the coach the following information: early indications concerning the race distance best suited to the swimmer’s biological feature and the reasonable athletic targets extending up to 4-5 years of career. Therefore, this analysis may represent a useful tool for programming training loads over a yearly basis and also for a reasonable long period of time.

Acknowledgment

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References

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The Relationship Between Seven Anaerobic Tests and Swim Performance

D.M. Rohrs, M.S.
J.L. Mayhew Ph.D.
C. Arabas, M.S.
M. Shelton, B.S.

Northeast Missouri State University
Kirkville, MO 63501

Abstract
The purpose of this study was to determine if specific tests of anaerobic power and capacity (APC) were better indicators of swim performance than general tests of APC. Thirty two NCAA Division II swimmers (13 male, 19 female) performed the vertical jump (VJ), Margaria-Kalameen stair climb test (M-K), seated shot put test (SSP), Wingate arm crank test (WAT), biokinetic bench single right and left arm pull (SPR and SPL), 30 second biokinetic bench power test (BBP) and a 30 second tethered anaerobic swim test in random order. Velocities were calculated from time trials in the 22.86 m (1V), 45.72 m (2V) and 91.44 m (3V) crawl stroke distances. The M-K, WAT peak power, SPR, SPL and BBP were significantly correlated to 1V, 2V and 3V (P<0.05) and the VJ was correlated to the 2V and 3V (P<0.05) for the males. For the females, the AST mean force was significantly correlated to 1V, 2V and 3V (P<0.05) whereas the M-K was significantly correlated to 1V and 3V (P<0.05). General as well as specific tests of APC were indicators of swim velocity for the males. For the females however, the AST seemed to be the best indicator of swim velocity. Before using tests of APC to assess sprinting ability coaches need to consider the group of swimmers. Sharp et al. (1982) found a significant correlation between arm power measured on the biokinetic swim bench and 25 yard (22.86 m) swim velocity whereas Costill et al. (1986) did not. The discrepancy was attributed to the sample of subjects. The ability level of Sharp et al.'s swimmers varied while Costill et al.'s subjects were homogeneous. In this particular study the females were a homogenous group whereas the males were considered heterogeneous. Our findings lead us to believe that a test which assesses the anaerobic capabilities for one group may not do so for another, depending on the ability level of the groups.

Introduction
The metabolic pathway used to supply energy during swimming depends on the distance of the event. In a 50 second maximal swim, such as the 100 meter crawl stroke event, anaerobic metabolism may account for 80% of the total energy yield (11). Since more than 75% of all swim competitions involve distances of 50, 100 and 200 meters, anaerobic metabolism is an important component to consider when evaluating swimmers.
Quantitative measures of anaerobic metabolism are difficult to obtain. Invasive measures (muscle biopsies and blood samples) are costly, demand knowledgable technicians and require a considerable amount of sophisticated equipment. Noninvasive measures of energy derived from phosphagen stores and the anaerobic breakdown of glycogen have been developed to eliminate the need for expensive equipment and complex procedures. Ideally these tests were designed to be short, simple, inexpensive and sensitive to intra-individual changes and inter-individual differences in anaerobic fitness.
It is questionable if a noninvasive test can assess an athlete's anaerobic condition if it is not specific to the athlete's sport (1). Therefore, the purpose of this study is twofold: (1) to determine if specific tests of anaerobic power and capacity (APC) (anaerobic power and capacity tests are defined as those that are an indirect measure of the phosphocreatine system and anaerobic glycolysis) were able to differentiate between faster and slower swimmers to a greater degree than general tests of APC and (2) to determine if these tests of APC were gender specific.
Table 1. Subject Characteristics

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<thead>
<tr>
<th></th>
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<th></th>
<th>FEMALE</th>
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<td></td>
<td>X</td>
<td>S.D.</td>
<td>X</td>
<td>S.D.</td>
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<tr>
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<td>20.0</td>
<td>1.0</td>
<td>19.4</td>
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<tr>
<td>(N = 13)</td>
<td></td>
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<td>(N = 19)</td>
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<tr>
<td>HEIGHT</td>
<td>1.83</td>
<td>0.11</td>
<td>1.68</td>
<td>0.05</td>
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<tr>
<td>(m)</td>
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<tr>
<td>WEIGHT</td>
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<td>9.0</td>
<td>64.0</td>
<td>8.5</td>
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<tr>
<td>(kg)</td>
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<tr>
<td>LBM</td>
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<td>7.5</td>
<td>50.0</td>
<td>6.1</td>
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<tr>
<td>(kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%BF</td>
<td>13.8</td>
<td>5.3</td>
<td>21.7</td>
<td>4.1</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>JV</td>
<td>1.78</td>
<td>0.15</td>
<td>1.56</td>
<td>0.06</td>
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<tr>
<td>(m/s)</td>
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<td></td>
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<tr>
<td>2V</td>
<td>1.69</td>
<td>0.15</td>
<td>1.50</td>
<td>0.06</td>
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<td>(m/s)</td>
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<tr>
<td>3V</td>
<td>1.57</td>
<td>0.11</td>
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<td>(m/s)</td>
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</table>

1V = velocity in the 22.86 meter distance
2V = velocity in the 45.72 meter distance
3V = velocity in the 91.44 meter distance

Table 2. Results of Seven Anaerobic Tests

<table>
<thead>
<tr>
<th></th>
<th>MALE</th>
<th></th>
<th>FEMALE</th>
<th></th>
</tr>
</thead>
<tbody>
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<td>X</td>
<td>S.D.</td>
<td>X</td>
<td>S.D.</td>
</tr>
<tr>
<td></td>
<td>(N = 13)</td>
<td></td>
<td>(N = 19)</td>
<td></td>
</tr>
<tr>
<td>VJ</td>
<td>0.49</td>
<td>0.09</td>
<td>0.37</td>
<td>0.05</td>
</tr>
<tr>
<td>(m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M-K</td>
<td>18.5</td>
<td>1.8</td>
<td>15.2</td>
<td>1.7</td>
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<tr>
<td>(WATTS/kg)</td>
<td>0.051</td>
<td>0.004</td>
<td>0.044</td>
<td>0.005</td>
</tr>
<tr>
<td>SSP</td>
<td>5.48</td>
<td>0.84</td>
<td>3.89</td>
<td>0.76</td>
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<tr>
<td>(WATTS/kg)</td>
<td>5.05</td>
<td>0.54</td>
<td>3.76</td>
<td>0.54</td>
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<tr>
<td>SPR</td>
<td>0.188</td>
<td>0.025</td>
<td>0.107</td>
<td>0.015</td>
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<tr>
<td>(kg/m/kg)</td>
<td>0.180</td>
<td>0.023</td>
<td>0.104</td>
<td>0.014</td>
</tr>
<tr>
<td>SPL</td>
<td>9.9</td>
<td>1.1</td>
<td>6.8</td>
<td>1.0</td>
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<tr>
<td>(WATTS/kg)</td>
<td>0.173</td>
<td>0.038</td>
<td>0.130</td>
<td>0.025</td>
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<tr>
<td>BBP</td>
<td>0.138</td>
<td>0.034</td>
<td>0.116</td>
<td>0.022</td>
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<tr>
<td>(WATTS/kg)</td>
<td></td>
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</tbody>
</table>

* P<0.01

Materials and Methods

Thirty-two NCAA Division II swimmers (13 male, 9 female), who were in their second month of training, served as subjects. Subject characteristics are presented in Table 1. Prior to participation, athletes received written and verbal explanations of the experimental procedures, and signed a consent form. Anthropometric variables included height, weight, and body density determined by underwater weighing (12) with residual volume predicted from age and height (9). Percent body fat (%BF) was derived from the Brozek equation (13).

Anaerobic power and capacity tests included the vertical jump (VJ), the Margaria-Kalaman stair-climb test (M-K), the seated shot put (SSP), the Wingate arm crank test (WAT), right and left arm pulls on the biokinetic swim bench (SPR and SPL respectively), a 30 second biokinetic bench power test (BBP) and a 30 second tethered swim test (AST). All tests were randomly administered over a four day period. In addition, subjects were timed in 22.86, 45.72 and 91.44 meter (25, 50 and 100 yard) crawl stroke distances from a push off to a hand touch on the pool wall. Times were recorded from a Colorado Timing System (System 3000, Loveland, Colorado) and converted to velocities.

Standing height and three VJ trials were filmed with a Panasonic videorecorder (PV 330) at a shutter speed of 1000 frames per second. Jump height was calculated using the Peak 2D Motion Measurement System (Peak Performance Technologies, Englewood, CO). The highest jump height was used for statistical analysis. Mean jump heights are presented in Table 2.

The M-K test was administered according to the procedures described by Fox et al. (7). Pressure sensitive switchmats placed on the third and ninth steps of an ordinary staircase activated a digital clock (Lafayette Instruments, Model #54035) sensitive to 0.001 seconds. The vertical distance traveled by the subject was 1.02 meters (each step 0.17 meters). The highest power value from the five trials was used for statistical analysis. Mean power values are presented in Table 2.

For the SSP, each subject was instructed to sit on the floor with his/her knees flexed and back against the wall. The subject propelled a 3.64 kg shot by using both hands and complete extension of both arms. Three practice trials preceded three actual trials, with the longest distance being used for statistical analysis. Mean distances the shot was thrown are presented in Table 2.

The WAT was administered according to the procedures described by Murphy et al. (15). A Monark cycle ergometer was placed on a platform at approximately chest level for each subject. The subject was secured to a chair with two velcro straps around the chest and waist. Handles replaced the pedals of the cycle ergometer. Revolutions of the flywheel were recorded from an infrared photoelectric cell (Lafayette Instruments, Model #63501-1R) connected to two digital counters (Lafayette Instruments, Model #54035). One counter recorded revolutions of the flywheel for the first five seconds of the test, and the other counter determined cumulative revolutions over the 30 second test period. Subjects were instructed to reach maximum cranking velocity as soon as possible at which time resistance was applied (.062 kp/kg for males and .048 kp/kg for females) (6). Values derived from the test included peak power (the highest power in the first 5 seconds of testing) and mean power (the average power during the entire 30 seconds). Mean power values presented in Table 2.
A biokinetic swim ergometer (Figure 1) (Isokinetics Incorporated) was used to determine individual single arm pull strength for the right and left arms (SPR, SPL). The apparatus is a semiaccommodating resistance device which can be preset at various velocities to provide constant acceleration in proportion to the force applied by the subject (18). For each single arm pull the subject was instructed to pull maximally on the hand paddle of the biokinetic bench. Work output was then recorded from the display on the front of the apparatus. Three trials for each arm were given in an alternating fashion, with the highest score recorded for each arm. In addition, a 30 second maximal anaerobic power test was completed on the biokinetic swim bench. The subject pulled the paddles with both arms in opposition (simulating the crawl stroke) as fast as possible for the entire period. Settings for the test were determined by the speed typically used while training on the bench during the season. These were four for the females and three for the males. Work values for the SPR and SPL and power values for the BBP are presented in Table 2.

A 30 second anaerobic swim power test (ASTP) was administered in two parts. For both parts of the test the subject was tethered to a calibrated force transducer by rubber surgical tubing (Figure 2). In the first part of the test, the highest force output from the transducer was recorded on a full scale, flat bed, chart recorder (Kip and Zonen, Model BD 40) while the subject swam as far as possible against the tether. Following a 15 minute rest, the second part of the test required the subject to swim against the previously determined force for 30 seconds. Peak force, the highest force in 30 seconds and mean force, the average force during the 30 second period were calculated from the resultant force curves. Actual power values could not be calculated due to the negative displacement of the swimmer as fatigue occurred. Force values are presented in Table 2.

Pearson product-moment correlations were calculated between the seven tests of APC and the three swim velocities. All tests except VJ were expressed relative to body mass. Student’s t-tests were used to evaluate gender differences.

**Results**

Swim velocities for the three crawl stroke events were significantly correlated with several of the anaerobic tests in both males and females (Table 3). The VJ, M-K, WATP peak power, SPL, SPR and BBP significantly correlated with swim velocities for the males. For the females, the ASTP mean force was significantly correlated to all three velocities whereas the M-K significantly correlated at the 22.86m and 91.44m velocities.

Males were significantly different from females in all

---

**Table 3. Correlations Between Anaerobic Tests and Swim Velocities In Male and Female Collegiate Swimmers**

<table>
<thead>
<tr>
<th></th>
<th>VJ</th>
<th>M-K</th>
<th>SSP</th>
<th>WATP</th>
<th>WATM</th>
<th>SPR</th>
<th>SPL</th>
<th>BBP</th>
<th>ASTP</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1V M</td>
<td>.59</td>
<td>.66*</td>
<td>.27</td>
<td>.64**</td>
<td>.49</td>
<td>.74*</td>
<td>.66*</td>
<td>.86*</td>
<td>.49</td>
<td>.23</td>
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<tr>
<td></td>
<td>.07</td>
<td>.45**</td>
<td>.27</td>
<td>.09</td>
<td>.37</td>
<td>.33</td>
<td>-.03</td>
<td>.31</td>
<td>.56*</td>
<td>.62*</td>
</tr>
<tr>
<td>2V M</td>
<td>.66**</td>
<td>.53**</td>
<td>.25</td>
<td>.53**</td>
<td>.45</td>
<td>.61**</td>
<td>.61**</td>
<td>.89*</td>
<td>.28</td>
<td>.11</td>
</tr>
<tr>
<td>F</td>
<td>-.13</td>
<td>.25</td>
<td>.36</td>
<td>-.14</td>
<td>.30</td>
<td>.30</td>
<td>-.15</td>
<td>.30</td>
<td>.34</td>
<td>.47**</td>
</tr>
<tr>
<td>3V M</td>
<td>.62**</td>
<td>.59**</td>
<td>.21</td>
<td>.54**</td>
<td>.32</td>
<td>.47</td>
<td>.49**</td>
<td>.88*</td>
<td>.36</td>
<td>.11</td>
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<tr>
<td>F</td>
<td>.12**</td>
<td>.40**</td>
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<td>.43**</td>
<td>.32</td>
<td>-.07</td>
<td>.42**</td>
<td>.37</td>
<td>.44**</td>
</tr>
</tbody>
</table>

* P <0.01  
** P <0.05

VJ  = vertical jump
M-K = Margaria-Kalamen stair climb
SPR = single pull right arm biokinetic bench
SPL = single pull left arm biokinetic bench
BBP = 30 second biokinetic power test
ASTP = swim test peak force
ASTM = swim test mean force
1V = velocity in the 22.86 meter distance
2V = velocity in the 45.72 meter distance
3V = velocity in the 91.44 meter distance
M = male
F = female
physical characteristics except age (Table 1). Further, males had significantly higher force, work and power outputs on all performance tests than females (Table 2).

Discussion

Noninvasive measures of anaerobic power and capacity (APC) have been developed as alternatives to invasive measures that require complex equipment and trained technicians. Noninvasive tests can be placed along a continuum from general to specific depending on the similarity of the test to the athlete's sport. As early as 1921, Sargeant (17) proposed the VJ as a test of general muscular power and indicated that it would differentiate between spirit and distance athletes regardless of sport. More recently Bar-Or (2) concluded that the Wingate test would quantify anaerobic metabolism for male athletes regardless of their sport. Our results indicate that the VJ was able to differentiate between faster and slower male swimmers (at the 45.72m and 91.44m distances) thus agreeing with the proposal of Sargeant. With the female swimmers however, the VJ was insignificant in its relationship to swimming velocity thus refuting the proposal of Sargeant. Wingate peak power (WATPP) was also able to distinguish between the two groups of male swimmers but showed the same trends with the females as did the VJ. It would appear that the so called general tests of anaerobic power are able to differentiate between faster and slower male swimmers with the opposite being true for the female swimmers. This finding could be due to the heterogenous makeup of the male swimmers which will be explained.

Margaria et al. (14) isolated the stair-run power test as a measure specific to leg and lower trunk muscle power. Recently, Gillespie and Keenum (8) proposed the SSP as a power test for the upper body. Following the more specific nature of these tests we would expect the M-K to be related to 22.86m velocity since the leg contribution during this distance is considerable (3). The M-K was found to be significantly correlated to all swim velocities for males and females (except the 45.72 meter distance for the females). Perhaps this is an indication that the faster swimmers have a more powerful lower body musculature than slower swimmers. We would also expect the SSP to be related to swimming velocities because it is a test of upper body power (8). This was not the case. The SSP was insignificantly correlated to all swim velocities for both males and females leading us to conclude that it cannot be generalized to the sport of swimming.

Specific to the sport of swimming, the SPR, SPL and BBP, measured on the biokinetic swim bench, have been suggested as possible indicators of swim power. Sharp et al. (18) found a correlation of r = .90 between 25 yard (22.86m) swim velocity and arm power measured from the biokinetic swim bench. Costill et al. (5) later refuted the previous finding when they noted an insignificant correlation (r = .24) between the same two variables. Costill et al. concluded that the previous significant relationship was due to the inclusion of a heterogenous sample of swimmers whose ability levels varied a great degree. Our findings however, agree with those of Sharp et al. (18). The SPR, SPL and BBP all significantly correlated to swim velocities for the males. The only significant relationship found for the females was between 91.44 meter velocity and the BBP (r = .42).

Costill et al. (5) found a significant correlation (r = .84) between swim power measured via a tether system in the water and 25 yard (22.86m) swim velocity. The authors concluded that swim power measured in the water was more specific to the propulsive forces of the crawl stroke than those measured on the biokinetic bench. Following this rationale, the AST has been proposed as the most sport specific test for swimmers (16). In the present study, however, neither the AST peak force (ASTP) nor the AST mean force (ASTM) was significantly related to any of the swim velocities for males (Table 3). These findings were contradictory to those of Costill et al., Hopper et al., and Rohrs et al. (5, 10, 16). One possible explanation for the insignificant relationships noted in the present study may have been the phase of training during which the measurements were taken. At the time of evaluation, all swimmers were engaged in aerobic (distance) training which could have decreased the potential for swim power output in the sprint swimmers and made the differentiation between faster and slower swimmers impossible. Indeed previous research (unpublished findings) indicated that male sprint swimmers increased their power output on the AST with a change from distance to sprint training, while the male distance swimmers remained stable in their power generation over the same training period. The ASTM appeared to be a better indicator of swim velocity for the females than males (Table 3). Training phase did not seem to affect or had a lesser affect on the females than the males.

The rationale for gender specific discrepancies on the other tests was not apparent. One explanation could be the sample of swimmers. There was considerable homogeneity among the female swimmers due to the availability of scholarships offered at the University where the research was conducted. For example, note the relatively small standard deviation in velocities for the females as compared to the males (Table 1). The men's team was not funded by scholarships leading to a more heterogenous group. This explanation would support the significant relationship found between the biokinetic bench and swim velocities. Perhaps, as Costill et al. (5) suggests, if the male swimmers were a more homogenous group these relationships would not have been found. It is not known whether male/female differences were entirely due to the make-up of the groups.
or gender related. Further research needs to be done on homogenous groups of male and female swimmers to determine if differences are still evident.

Conclusions

In summary, a variety of tests ranging from general to specific (VJ, M-K, WAT peak power, SPR, SPL and BBP) were indicators of swim velocity for the males. For the female swimmers, the AST seemed to be the best indicator of velocity in 22.86m, 45.72m and 91.44m events. Christensen and Smith (4) suggest that in-water testing may be more valuable than testing on the Biokinetic Swim Bench. In other words, in-water testing should be used rather than dry land testing. Our findings lead us to believe that a test which assesses the anaerobic capabilities for one group may not do so for another. Before any tests are used for evaluation, consideration must be given to the group of swimmers to be tested.

References

1. Swimmer and Team  
   — By Don Gambril and Alfred Bay  
   Practical, how-to information on the swim team. 117 pages.  
   $11.95

2. Swimming Faster  
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