

ISSN: 0747-5993  
Vol. 6, No. 3, Fall 1990

# THE JOURNAL OF SWIMMING RESEARCH

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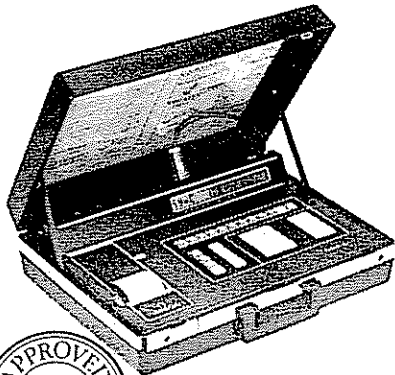
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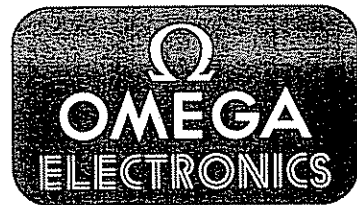
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A publication of the ASCA in cooperation with the USS Sports Medicine Committee

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THE JOURNAL OF SWIMMING RESEARCH entitles the subscriber to 4 issues as they are published (not necessarily quarterly) by the American Swimming Coaches Association from 1 Hall of Fame Drive, Fort Lauderdale FL 33316. Telephone (305) 462-6267. Subscription rates are \$55.00 (foreign), \$45.00 (Canada & Mexico), and \$35.00 (USA). This 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

This issue contains three manuscripts, two of which (Ria and Rielly) concern the role of muscle strength in swimming and another (Ryan) which describes the results of a season-long testing of the blood lactate responses to a standardized swimming set.

The first manuscript by Ryan provides excellent detail concerning how blood lactate determinations were used to evaluate the training progress of the female swimmers at the University of Texas. The finding that the swimming speed corresponding to a blood lactate concentration of 4 mM increased only during the first six weeks of the season with a plateau-effect over the remainder of the training is of primary importance. The authors make the point that once training volume had been increased to roughly 9,000 yd/day, no further adaptation of the blood lactate response was gained from additional yardage up to about 12,000 yd/day. This does not mean that *nothing* can be gained from higher volumes of work, but does indicate that this single component of performance is not further enhanced (in these swimmers with their training program) by volumes of work in excess of 9-10,000 yd/day.

The second paper by Ria describes a study conducted with 11-13 yr old French swimmers to reassess the role of mechanical power during swimming in determining sprint performance (50 and 100 m freestyle). Using a 6 second measure of in-water power output, the authors conclude that the ability of the arms to generate power is a significant contributor to 50 and 100 m performance even in this age-group. These results confirm those of earlier studies that used older swimmers with more diverse performance abilities. An intriguing possible application is also suggested in the way power was measured: if propulsive power is high for a swimmer, but his/her peak 6 sec velocity is low, then this may indicate a need for technique work designed to reduce body drag and improve streamlining.

The third paper by Rielly describes isokinetic measurements of strength/power of various isolated muscle groups thought to be heavily involved in swimming. Measurements of stroking characteristics were also performed. In this group of subjects, there were no differences between the faster and slower swimmers in muscle strength/power but the faster swimmers achieved a higher distance per stroke at peak speed. These findings underscore the importance of how the available power is applied (mechanics of propulsion) and the large role that must be played by body drag in determining a swimmer's performance potential.

RICK SHARP

## Blood Lactate Profile Throughout a Training Season in Elite Female Swimmers

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### Abstract

*The blood lactate versus swimming velocity profile was established in fourteen female swimmers from the University of Texas Women's Varsity Swim Team at two week intervals during the collegiate season from September to March 1987. After a standardized warm-up period, each athlete completed 3 x 500 yard swims with thirty seconds rest between bouts, at intensities selected to elicit blood lactates in the range of 2-15 mM. Finger stick blood samples were collected during the thirty second rest intervals and analyzed using the Kontron 640 Lactate Analyzer. The swimming velocity eliciting a blood lactate concentration of 4 mM was identified in the profile of each athlete. After training at an average of 35,000 yds/wk (early September), the mean ( $\pm$  /-SD) velocity at 4 mM was 1.32 + /0.12 yds/sec. When the training load was increased to an average of 54,000 yds/wk, velocity at 4 mM increased significantly ( $p < .05$ ) to 1.52 + /0.08 yds/sec. The swimming velocity eliciting 4 mM remained between 1.52 and 1.55 yds/sec for the remainder of the season despite increases in training yardage to an average of 72,000 yds/wk. The findings indicate that increases in the velocity eliciting a blood lactate of 4 mM occur early in the season in response to an increase in training yardage to moderate levels. Increases in training yardage above 54,000 yds/wk during the remainder of the training season did not alter the swimming velocity eliciting a blood lactate of 4 mM.*

### Introduction

The velocity maintained during competition in endurance events such as running, cycling, walking and swimming can be predicted with reasonable accuracy from the determination of the velocity at which lactate concentration increases to the 2-4 mM level within the blood (i.e.: blood lactate threshold) (1,6,9). The conceptual basis for this prediction is that competitive pace is selected according to the degree of muscular fatigue experienced, due largely to factors associated with lactate production within the exercising muscle (6,7). It is thought that both the velocity of performance as well as that eliciting the blood lactate threshold will increase as a result of training induced adaptations which increase the muscle's ability to produce energy aerobically (8,9) thus reducing the rate of muscle glycogen use and lactate formation (7). One key muscular adaptation responsible for this improvement in endurance performance ability is increased mitochondrial density and oxidative enzyme activity within the trained muscle fibers (7).

In the present study, the velocity eliciting the blood lactate of 4 mM while swimming was monitored periodically throughout the competitive season in a group of elite female swimmers. The purpose of this investigation was to determine if increase in the total yardage swum during training resulted in improvements in the velocity which elicited a blood lactate of 4 mM.

### Methods

The subjects were twenty-five females that comprised the University of Texas Varsity Women's Swim Team. Fifty percent of the subjects were identified as world-class athletes. There were eight Olympians, World Championship or National Team members within the squad. Since the Women's Team had won the NCAA Division I National Championship title for the last three years prior to this study, the athletes comprising this squad were considered elite. The subjects who participated in

the study were all volunteers, in excellent health, and ranged in age from 18 to 24 years. The information in the study was distributed to the swimmers during the course of the data collection.

#### *Time Periods for Data Collection*

The data for this study were collected at two week intervals during the period from September 1986 to March 1987. It was decided that weekly testing would be too frequent considering the expense, amount of time necessary to test, and the reduced training time as a result of testing. The testing dates used in this paper for statistical comparison include: September 29, October 27, November 24, 1986 and January 12, January 26, and February 17, 1987. Testing was done on Monday afternoon, after a Sunday with no training, to insure that the athletes were rested. Monday morning's practice was at an easy pace and consisted of slow, aerobic swimming (3500 yards in an hour and a half). This reduced the possibility that the morning's training session would fatigue the athletes and as a result interfere with the afternoon testing.

#### *Warm-Up Procedure*

All athletes participated in a standardized warm-up each time the testing procedure was implemented. In a pilot study, inconsistent warm-up caused blood lactate levels to vary individually during the testing procedure and made comparisons between individual tests over the course of a season invalid. The warm-up consisted of 4 X 100 yard freestyle swims on 1:30. This was followed by a 300 yard kick/pull/swim. Next, 8 X 50 yard swims were done on 1:00. The warm-up was completed by a 100 yard easy swim and totaled 1200 yards. The perceived intensity for these athletes was low to moderate at approximately 60% to 80% of maximal oxygen uptake (i.e.; VO<sub>2</sub> max).

The initial blood lactate sample was taken after the warm-up procedure in order to quantify the blood lactate concentration values before the swim testing. This was done five minutes after the swimmers finished their warm-up. During the five minute interval, the swimmers got out of the water, dried off, and while they were waiting to give a blood sample they were instructed about the testing procedure and reminded of the requirements that their swim had to meet in order for the data to be valid.

#### *Testing Protocol*

The testing protocol involved three 500 yard (y) swims. The 500 y distance was chosen because its duration was long enough to allow the lactate levels in the blood to become reflective of the muscle. The swims were done at increasing levels of intensity as the swimmers were instructed to make the first swim easy and aerobic, the second swim at a pace close to their perceived or estimated lactate threshold, and the final swim an all out effort.

All three swims were to be evenly split, so that the swimming pace was consistent throughout the 500 y distance. One hundred yard split times were kept for all swims to see that steady state was maintained throughout each swim. Thirty seconds rest was given between each 500 y swim. During this thirty second rest a blood sample was taken. Each swimmer was assigned a test form and a timer at the beginning of the session. On this form was the swimmer's name, the date, the type of test done, and the stroke that the swimmer used. The times for each swim and the split by 100 y for each 500 y swim, plus the correlating blood sample number were recorded on the form. The swimmers were assigned a timer who recorded the splits, the final time, and the blood sample numbers. The timer was responsible for telling the swimmer when to start a swim, to notify the blood collectors when a sample was needed, to give the swimmer their 500 y splits, and to record all of the data on the swimmer's form.

In order for the data to be considered valid, the 500 y swims had to be performed at a constant velocity. If the swims were done at an uneven velocity there was the possibility that lactate values would fluctuate in the blood and muscle. If any of the 500 y swims were not evenly split, the test was invalidated for that athlete. Evenly split swims were defined as no more than 1.5 second variances between 100 y intervals of the 500 y swim.

#### **Testing Protocol**

1. 1200 y warm-up swim
2. 5 minute rest
3. pre-test blood sample
4. 500 y swim-aerobic pace
5. 30 second rest for blood sample
6. 2nd 500 y swim-threshold pace
7. 30 second rest for blood sample
8. 3rd 500 y swim-maximum
9. 30 second rest for blood sample

#### **Blood Analysis**

The blood analysis for lactate concentration was done using a Kontron 640 Lactate Analyzer. This analyzer was found to be valid ( $r = 0.94$ ) as determined by comparison with blood samples analyzed for lactate using a spectrophotometric method (5).

The use of the Kontron 640 Lactate Analyzer required a specific blood collection protocol. Blood was collected in a 40 microliter (ul) capillary tube. This tube was filled from top to bottom, devoid of air bubbles and then placed in a diluting capsule that contained 80 ul of 1% sodium azide solution. Bubbles in the tube, incomplete filling, or dilution by water were all avoided because they represented potential sources of error in computing the lactate concentration in the sample. The solution in the capsule was necessary to hemolyze the red blood cells and to

keep the blood from coagulating. This also caused glycolysis in the red blood cell to cease and thus stopped additional lactate production after the sample has been collected (10).

Blood was obtained by finger stick with an autolet and disposable needle. The finger was wiped dry, pricked, and then a blood sample was collected in the 40 ul capillary tube. The sample was placed in a diluting capsule and labeled according to the athlete and swim from which it was collected. The samples were run through the lactate analyzer within two hours after collection. The analyzer was calibrated before each set of samples were processed. This was done with known standards of 5 mM and 15 mM lactate. The purpose of running two standards was to maintain linearity with the machine. The samples were injected into the machine one at a time and a value was read from the machine's digital display. This value was multiplied by the dilution factor and the lactate concentration found in the sample was obtained.

Initially, this study resulted in the collection of over 1100 blood samples. Five samples were taken during nine testing sessions for twenty-five athletes. There were testing sessions in which athletes did not participate because of injury or illness. To reduce the data so that there were no missing points, only those athletes who completed the same six tests were used. To eliminate confusion caused by the different velocities associated with each stroke, only data from freestyle tests were used. This reduced the participant number to fourteen.

#### *Analysis of the Blood Lactate vs Velocity Profile*

Blood lactate concentration was determined for the pre-test sample and the three blood samples obtained after each 500 y swim. These values were graphed against the velocity of each bout. The velocity which elicited a blood lactate concentration of 4 mM was identified in each curve. This procedure was followed for every swimmer at each of the six periods.

Since only four points were used in graphing the lactate vs velocity relationship, it was difficult to establish a true blood lactate threshold defined as the initial curvilinear increase in lactate or even a 1 mM increase in lactate above baseline (1,6). It was possible, however, to identify the velocity eliciting a fixed blood lactate of 4 mM from each individual graph.

#### **Statistical Analysis**

The velocity corresponding to the blood lactate concentration of 4 mM was identified for all swimmers during each of the six testing sessions. Mean velocities at 4 mM were compared using a single factor repeated measure analysis of variance. Significant difference between mean values were identified using Tukey's post-hoc analysis with  $p < 0.05$ .

#### **Results**

The weekly training distance during the two weeks prior to the first testing session averaged 35,000 yards/week. This distance increased to 54,000 yards/week during the two week prior to the second testing (Table 1). The training yardage averaged 46,000 yards/week before the third test, 67,000 yards/week before the fourth test, 72,000 yards/week before the fifth test and was reduced to 40,000 yards/week before the sixth test.

Table 1  
Weekly Training Yardage for the Two Weeks  
Prior to the Testing Date

Testing Date:	Yardage
09/29/86	35,000
10/27/86	54,000
11/24/86	46,100
01/12/87	67,800
01/26/87	72,000
02/17/87	40,000

Yardage volume reflects training six days a week, except for the period before the testing data of 9/29/86, which reflects training five days a week. Values are not reflective of training groups (sprinters, middle, distance) but an average of the subjects.

The swimmers' mean velocity, at a blood lactate concentration of 4 mM during the first testing session was  $1.32 \pm 0.12$  yds/sec. It increased significantly ( $p < 0.05$ ) by the second testing session to  $1.52 \pm 0.08$  yds/sec (Table 2). During the period from the second through sixth session (10/27/86 - 2/17/87), the mean velocities which elicited a 4 mM blood lactate concentration were not different with values ranging from  $1.52 \pm 0.08$  to  $1.55 \pm 0.08$  yds./sec.

Table 2  
Velocity (yd/sec) at 4 mM Lactate Over  
6 Testing Period

SUBJ.	9/29/86	10/27/86	11/24/86	1/12/87	1/26/87	2/17/87
1	1.33	1.54	1.58	1.59	1.59	1.59
2	1.44	1.44	1.58	1.55	1.58	1.60
3	1.53	1.65	1.59	1.67	1.60	1.56
4	1.09	1.44	1.47	1.49	1.44	1.47
5	1.36	1.53	1.50	1.47	1.46	1.45
6	1.28	1.56	1.62	1.64	1.64	1.64
7	1.23	1.55	1.52	1.53	1.53	1.58
8	1.21	1.50	1.50	1.47	1.50	1.46
9	1.42	1.46	1.47	1.45	1.50	1.46
10	1.32	1.39	1.64	1.68	1.55	1.60
11	1.33	1.59	1.56	1.53	1.60	1.54
12	1.14	1.42	1.45	1.55	1.42	1.48
13	1.33	1.50	1.50	1.47	1.48	1.49
14	1.44	1.64	1.61	1.64	1.66	1.62
Mean	1.32*	1.52	1.54	1.55	1.54	1.54
+/-SD	0.12	0.08	0.06	0.08	0.07	0.07

\*Significantly different from all the other values ( $p < 0.05$ ).

## Discussion/Conclusion

The major finding of this study was that the swimming velocity eliciting a 4 mM blood lactate concentration increased from  $1.32 \pm 0.12$  y/sec to  $1.52 \pm 0.08$  y/sec when training yardage was increased from 35,000 y/week to 54,000 y/week early in the season. It then remained remarkably stable throughout the remainder of the season despite fluctuations in training yardage from 40,000 to 72,000 y/week. During the three weeks prior to the initial testing on 9/29, these women were recovering from their previous year's competitive summer season by performing low intensity swimming averaging only 35,000 y/week. This three week period of reduced training yardage and intensity appears to have been of sufficient duration to cause a partial "detraining" of their blood lactate threshold and oxidative enzyme activity. This agrees with the observation that these systems have a half-life response of approximately 10-12 days (3). It therefore appears that swim training of less than 35,000 y/week, at low intensity, is insufficient to maintain a high level of conditioning, reflected in the velocity eliciting a blood lactate concentration of 4 mM.

When training yardage was increased from 35,000 to 54,000 y/week, and the intensity of training was also increased during the subsequent month, the velocity eliciting a blood lactate of 4 mM increased 15% (i.e.; 1.32 to 1.52 y/sec;  $P < 0.05$ ). This large and rapid improvement may reflect the ability of partially detrained athletes to quickly redevelop a high level of maximal oxygen uptake and mitochondrial enzyme activity (2,3).

A remarkable finding of this study was that the blood lactate profile of these elite women did not change during the 4.5 month period between 10/27 and 2/17. This was despite increases in training yardage up to 72,000 y/week during winter vacation and subsequent reductions in yardage to 40,000 y/week as the peak competitive season approached. Therefore, it appears that the rationale for increasing training yardage above 54,000 y/week can not be based upon promoting adaptations which reduce blood lactate concentration when swimming.

Theoretically, the velocity eliciting a blood lactate concentration of 4 mM provides information regarding the pace at which the exercising muscle become stressed sufficiently to accelerate muscle glycogen breakdown, resulting in lactate accumulation within muscle and blood (1). Therefore, one interpretation of the fact that the blood lactate profile was not changing from 10/27 to 2/17 is that there was no further adaptation within the swimming musculature which reduced lactate production. The most important training induced muscular adaptation responsible for reducing muscle glycogen breakdown and lactate formation is the increase in mitochondrial content and oxidative enzyme activity (7). It has been observed that alterations in the blood lactate threshold of well trained endurance athletes is paralleled by changes in oxi-

dative enzyme activity (3). Thus, it is possible that the lack of change in the blood lactate profile with increased training yardage, reflects a failure to promote continued increases in mitochondrial enzyme activity.

Support for this possibility comes from animal studies which have observed that moderate training of more than 60 min per day did not result in increased mitochondrial activity (4). If people respond similarly, it would be predicted that moderate to intense swimming of more than 60 min duration or about 40,000-50,000 y/week would not be effective in promoting further mitochondrial development. This agrees with our present finding that the blood lactate response to swimming improves when training is increased above 35,000 y/week but not when training yardage is within the range of 54,000-72,000 y/week. It should be realized that the intensity of training dictates muscle fiber recruitment, which is of major importance in the magnitude of mitochondrial adaptation (4). That is, optimal mitochondrial adaptations can occur with short duration (i.e.; 15-30 min day) high intensity training (4). However, it appears that the intensity of training during the first few weeks of the season in these elite women was not sufficiently high to promote optimal adaptation with only 35,000 y/week of training.

In summary, these findings indicate that increases in the swimming velocity eliciting a blood lactate of 4 mM occur early in the season in response to an increase in training yardage to moderate levels. Increases in training yardage from 54,000-72,000 y/week during the remainder of the training season did not alter the blood lactate profile. Therefore, we were unable to identify the adaptive physiological responses that may occur in elite swimmers training more than about 8,000 y/day.

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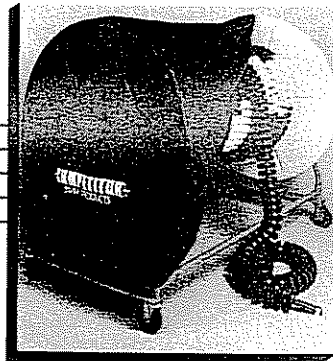
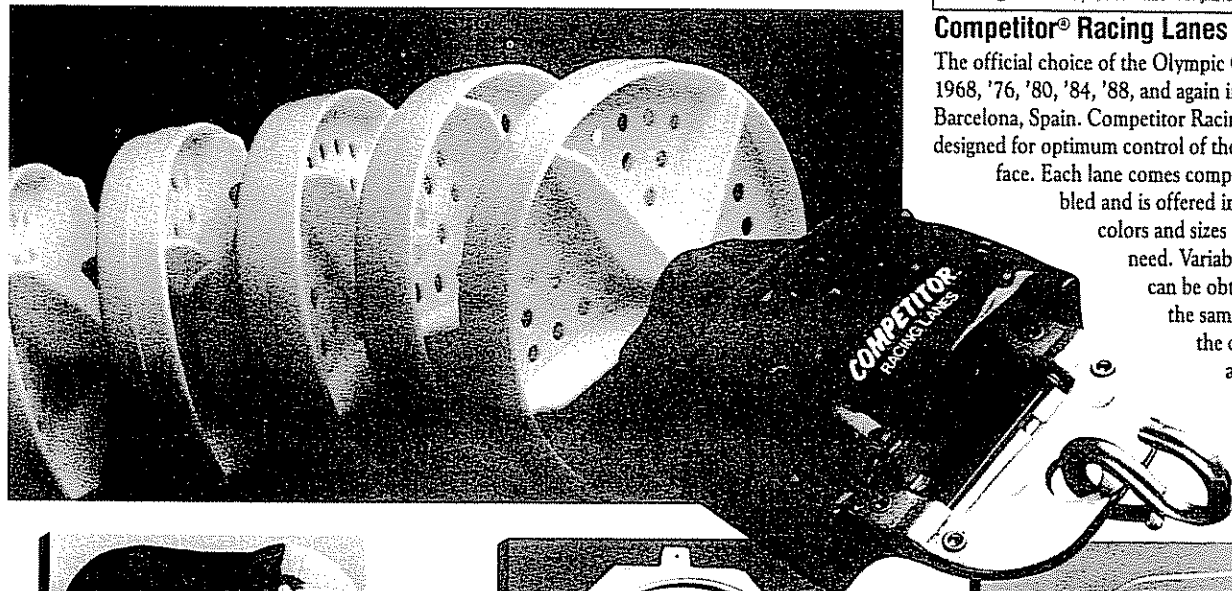
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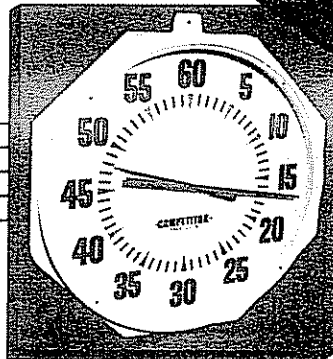
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# Assessment of the Mechanical Power In the Young Swimmer

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## Abstract

*An evaluation test of the external mechanical power of the swimmer is proposed in the perspective of an analysis of the biomechanics factors in sprint performance. This test is validated with 20 young male club swimmers 11-13 age group.*

*The external mechanical power (EMP) is obtained by multiplying the average propulsive strength by the average speed recorded in a 6 second maximal effort in crawl swimming.*

*The mechanical power found is : 71.2 w ( $\pm$  17.3)*

*The body weight relative mechanical power : 1.80 w.kg<sup>-1</sup> ( $\pm$  0.44)*

*The mechanical power put in the water only reaches 23% of that recorded with the cycle ergometer.*

*A significant relationship is observed between EMP and sprintspeed : 50 m,  $r = 0.70$  ; 10 m,  $r = 0.72$  ( $p < 0.05$ ).*

*The body weight relative EMP is correlated with the sprint : 50 m,  $r = 0.70$  ; 100 m,  $r = 0.80$  ( $p < 0.05$ ).*

*A good swimmer must have a high EMP and a good weight power ratio to make an excellent sprint performance.*

## Introduction

A coach eager to improve the efficiency of the swimmer's propulsive movement carries out biomechanical and energetic tests. Swimming efficiency can be defined by the ratio of the external mechanical power (EMP) to energy expenditure in the same time ( $\dot{V}O_2$ ). The purpose of this study is to research the swimmer's EMP. A test associating the swimmer's propulsive force (FP) with his swimming speed (V) is therefore proposed to evaluate the EMP put in by the swimmer in a 6 s maximal effort. The relevance of the test is verified by the correlation between EMP with 50 and 100 meter sprints.

MYASHITA (3) had calculated EMP from the speed recorded by a 16 mm film and the drag met by the swimmer. This author found that in breaststroke the legs' power is superior to that of the arms : by 30% in the beginner and 20% in the trained swimmer.

SHARP (5) for his part evaluates the arm power with a biokinetic swimbench during a 60 s maximal effort. He notes that the maximal armforce is obtained through a 2.4 m.s<sup>-1</sup> speed. The correlation between the arm-power and the 25 m sprint is significant at  $r = 0.90$ .

COSTILL (1, 2) by using an isokinetic apparatus adapted to swimming found that female swimmers power is 28% lower than that of male counterparts ( $P = 0.65$  w.kg<sup>-1</sup> in the male ;  $P = 0.51$  w.kg<sup>-1</sup> in the female). He also establishes an interrelationship between swimming power and the short sprint (13 m) at  $r = 0.84$  and he confirms that the improving of the performance (3%) is indeed linked to the increase of muscular strength (18%).

At last, TOUSSAINT and HOLLANDER (6) recorded the swimmer's work by summing the swimmer's impulses made with paddles fixed on the pool bottom and equipped with sensors. Besides these authors measure the  $\dot{V}O_2$  expenditure during an exercise made at equal speed. Thus they define swimming efficiency : 9% for the whole stroke and 15% for the armstroke.

## Methodology

### Subjects

The experiment was carried out with 20 unspecialized prepubertal boys (11-13 age group) who get a 4 hours training a week. The biometric data of these subjects are reported in Table 1.

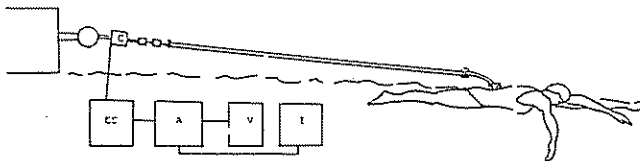
**Table 1**  
Biometric data of 20 prepubertal boys swimmers 11-13 age-group.

Subjects	Size (cm)	Weight (kg)	Age (Years)	% Fat	Biacromial diameter (cm)	Biliac diameter (cm)	Hand area (cm <sup>2</sup> )
1	134.5	30.2	11	13.1	30.1	20.5	101.29
2	144.9	43	11	27.2	29.6	21.4	133.33
3	138	30.2	12	10.2	31.2	21	106.56
4	164.7	50.8	11	11	34.1	23.3	154.46
5	148.5	39.2	12	19.8	33.6	23.9	154.46
6	148.4	37.2	11	13.1	33.1	23.4	131.95
7	143.2	35.8	11	13.2	30.8	22.3	109.99
8	146.7	48	12	28.6	33.2	23	112.34
9	146.4	39.6	13	15.7	32	23	113.22
10	152.3	37.6	12	12.5	33.7	22.7	114.26
11	143.9	31.2	12	12.5	31	22	106.93
12	150.2	39.8	13	17.5	31.5	23.5	108.46
13	135.8	27.8	9	10.75	30.5	21.6	94.08
14	131.7	23.6	10	9.3	28.9	19.6	89.60
15	171.6	56.6	13	16.7	37.2	26.1	151.08
16	155	44.4	13	20.5	34.3	23.6	121.96
17	155.3	41.8	12	19.9	33.8	23.1	129.08
18	154.9	37	12	13.1	34.4	24.5	126.12
19	136.4	31.6	11	13.4	30.4	21	102.68
20	149.5	42	12	21.5	31.5	21.9	109.66
X	147.6	38.4	11.5	16	32.24	22.57	118.6
SD	9.7	7.8	0.12	5.3	2	1.4	18.5

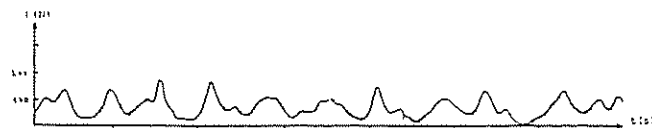
**Procedures**

*Measuring the propulsive force (Figure 1)*

The propulsive force is measured on a swimmer tethered at the waist to a pole connected to a force sensor. The tension generated by the sensor is converted into a numeric signal. The computer shows the diagram of the



**Figure 1.** Apparatus to measure the swimmer's propulsive force  
c : sensor  
cs : signal converter  
A : Apple II  
V : video  
I : writer

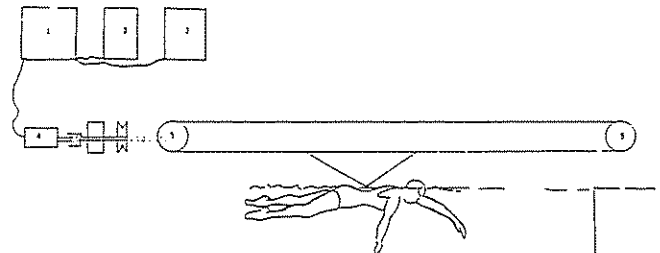


**Figure 2.** The propulsive force during the attempt of 6 s.  
Swimmer reference : L  
Attempt 1  
Scale Y = 100 N, X = 1 s  
t 0.00 to 0.07 s      Max : 162 N      area : 62 N\*s

force in relation with time and calculates the area of the graph during the whole propulsion. The frequency of the signal is 100 Hz (Figure 2). The calibration of the sensor is made by measuring the output tension in relation to the weights. Accuracy : 1N.

*Measuring instant swimming velocity (Figure 3)*

The swimmer is connected to an unstretchable cable that curves around 2 pulleys fixed at either end of the pool. One of the pulleys drives an optical imulsion generator which emits a signal at every 0.17 cm. The



**Figure 3.** Apparatus to measure the instant speed :  
1—computer  
2—video  
3—writer  
4—speed sensor  
5—pulley  
6—unstretchable cable

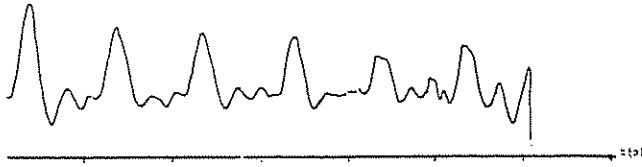


Figure 4. Instant velocity.

Max.  $V = 1.73$  m/s

Min.  $V = 0.37$  m/s

av.  $V = 0.826$

Sd = 0.074

Scale : Y = 1 m/s, X = 1 s

signal is processed on Apple 2 computer. The software calculates the instant velocity, the average velocity and the standard deviation during the attempt (Figure 4). The speed sensor is calibrated by speed and time measuring. The control of the speed on the screen is made by timing two landmarks on the cable 10 m apart. Accuracy : 0.01 m.s<sup>-1</sup>. The time calculated by the computer between the impulses struck on the keyboard for one minute is adjusted to real time. Accuracy : 1.10<sup>-2</sup> s. The measuring of instant swimming velocity allows to obtain the peak sprint speed, the minimal speed and the average speed for each attempt.

Two attempts are made in either case and the best one is kept.

#### Calculation of the external mechanical power

In order to calculate the EMP the product of the average speed (over 6 s.) by the average force (over 6 s.) was made for each child.

The average force put in during the 6 s. effort is obtained by dividing the force integral by the time. The average speed is given by the software. The average power during the test is :

$$EMP = F_m \times V_m$$

It is therefore an average EMP calculated during a 6 s. maximal effort.

The power is related to subject's weight to determine the relative power. The correlation between the EMP in the water and the sprint performances are analyzed by linear regression. The EMP calculated in the water is compared to EMP obtained on an ergometer cycle by the test force-velocity during a 6 s. effort.

#### Results

The results of the speed recorded in 50 and 100 m sprints, the force and speed averages in 6 s tests are shown in Table 2.

Table 2

Velocities, forces, EMP (in water and on ergometer cycle) of 20 young boys swimmers 11-13 age group.

Subjects	V1	V2	V	F	EMP	EMPr	ECP	ECPr
1	1.28	1.12	1.22	35.2	42.95	1.42	248	8.26
2	1.28	1.25	1.25	45.26	56.6	1.32	310	7.21
3	1.39	1.37	1.28	47.8	61.2	2.03	313	10.36
4	1.43	1.28	1.39	85.5	118.8	2.34	522	10.27
5	1.43	1.42	1.32	64.8	85.5	2.18	275	7.01
6	1.25	1.24	1.34	58.6	78.5	2.11	255	6.85
7	1.35	1.32	1.32	57.75	76.2	2.13	346	9.66
8	1	0.77	0.93	50	46.5	0.97	389	8.1
9	1.56	1.38	1.3	57.25	74.4	1.5	375	9.46
10	1.39	1.25	1.33	54.7	72.75	1.93	280	7.45
11	1.43	1.33	1.23	52	64	2.05	236	7.56
12	1.52	1.38	1.34	62.5	83.75	2.1	327	8.21
13	1.19	1.08	1.33	31.4	41.8	1.5	179	6.43
14	1.04	0.82	1.22	18.51	22.6	0.96	147	6.23
15	1.43	1.4	1.46	82.5	120	2.13	432	7.36
16	1.43	1.32	1.36	64	87	1.96	437	9.84
17	1.39	1.28	1.3	79.4	103.2	2.47	244	5.83
18	1.28	1.21	1.3	58	75.4	2.04	299	8.08
19	1	0.88	1.01	37.2	37.5	1.19	242	7.66
20	1.52	1.15	1.55	49.3	76.4	1.82	305	7.26
X	1.33	1.21	1.29	54.6	71.2	1.80	308	7.97
SD	0.16	0.19	0.13	16.4	25	0.44	88	1.30

V1 : maximal velocity 50 m (m.s<sup>-1</sup>)

V2 : maximal velocity 100 m (m.s<sup>-1</sup>)

V : average velocity during the test (m.s<sup>-1</sup>)

F : average force during the test (N)

EMP : external mechanical power (W)

EMPr : EMP adjusted weight (W)

ECP : Ergometer cycle power (W)

ECPr : ECP adjusted weight (W)

The average force for the whole group is : 54.6 N (sd = 16)  
 The average speed recorded is : 1.29 m.s<sup>-1</sup> (sd = 0.13)  
 The EMP is : 71.2 W (sd = 25)

This research is performed in a more general outlook of the study of the effects of training on a young swimmer. The children are besides analyzed in energetics tests on the ergometer cycle :  $\dot{V}O_2$  max, wingate test, and force-velocity test, from which the ergometer cycle power (EMC) produced by the legs is calculated namely 308 w (average for the whole group) ; sd = 88.0

The relative power related to subject's weight are in the water : 1.80 w.kg<sup>-1</sup> (sd = 0.44), with ergometer cycle : 7.97 w.kg<sup>-1</sup> (sd = 1.3)

The EMP obtained in the whole swimming is only 23% of that obtained with the ergometer cycle, legs only.

The correlations found with the sprint performances are given in Table 3.

Table 3  
 Values of r between EMP and SPRINTS (p ≤ 0.05)

Power \ Sprint	50	100
50	0.70	0.70
100	0.72	0.80

Figures 5 and 6 show the linear regression between EMP<sub>r</sub> and the sprint performances. The relative EMP<sub>r</sub> related to the 50 and 100 m sprint offer similar correlations: r = 0.70 et 0.80.

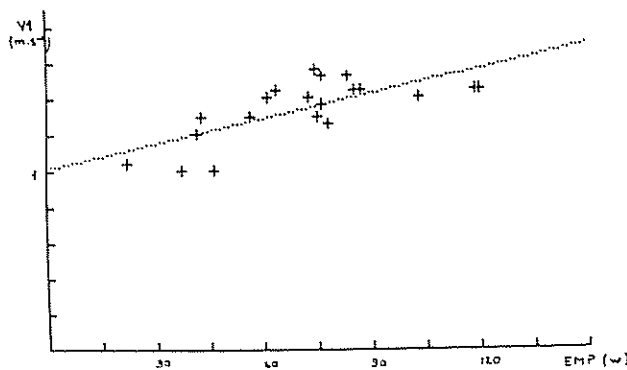


Figure 5. Power related to 50 m sprint.  
 r = 0.70 (p < 0.05)  
 X = EMP (W)  
 Y = V1 (m.s<sup>-1</sup>)  
 n = 20

The EMP in the pool was compared to the ergometer cycle power ECP. The result of the correlation is : r = 0.68 (Fig. 7).

**Discussion**

The EMP test appears as being significant of swimming performance. This test is representative of the swimmer's

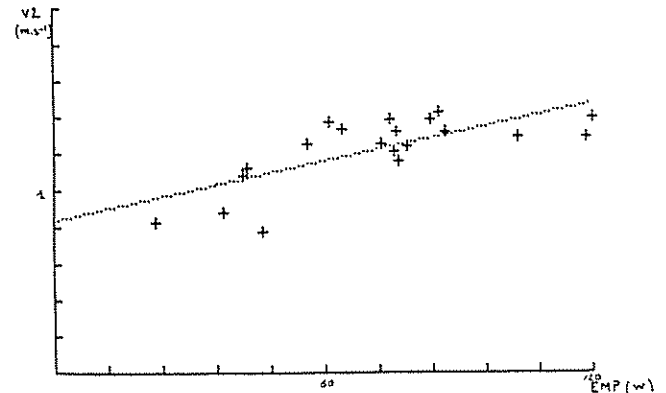


Figure 6. Power related to 100 m sprint.  
 r = 0.72 (p < 0.05)  
 X = EMP (W)  
 Y = V2 (m.s<sup>-1</sup>)  
 n = 20

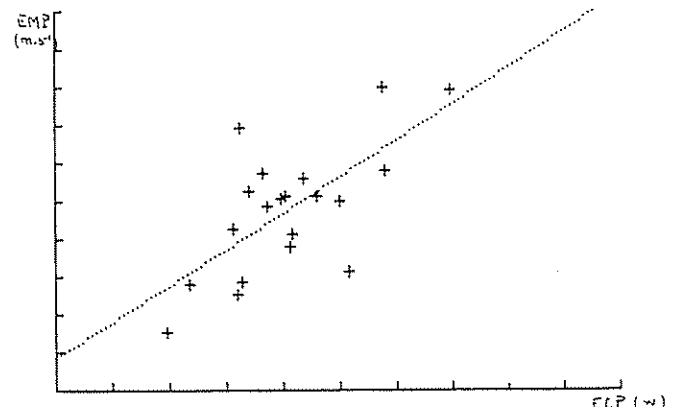


Figure 7. Power in the water related to power ergometer cycle.  
 r = 0.68 (p < 0.05)  
 X = ECP (W)  
 Y = EMP (W)  
 n = 20

propulsive force and of the speed achieved. It allows to assess his muscular strength and technical efficiency in a 6 s effort.

Yet, it may be noticed that it is not surprising to find an interrelationship between EMP and sprint since there is already a correlation between speed peak and the 50 m sprint with r = 0.76. All the more so as the product of the speed peak by the force is also correlated with the sprint. Let us notice that this correlation diminishes.

In a previous study it was shown that the impulse, that is to say the movement quantity per cycle was a more significant factor of the sprint than the strength peak : r = 0.81 with 33 swimmers of 3 national, country and club levels (RIA, 4).

The correlations found with the sprint performances are yet weaker than those noted by SHARP (r = 0.90) and COSTILL (r = 0.84). It should be remembered that these authors used shorter sprints (25 m and 13 m) than those we personally chose (50 m and 100 m). The ener-

getic processes required are different. Finally the young swimmer's average EMP (71 w) seems to be high compared to COSTILL's results with grown ups: 74.5 w for males and 41 W for females. Different procedures could explain this fact : COSTILL on his part uses isokinetic apparatus with a constant speed whereas we for ourselves analyze an instant variable speed through the test. Besides our force measuring is obtained with a tethered swimmer. It is to be noted that our strength and speed measures come from 2 distinct experimentations with flows that are not exactly identical.

Exceptionally a swimmer with a big EMP (118.8 w) may have a modest performance (34 s per 50 m). One may then suppose that the relation distance per stroke-frequency is not adapted to the performance of reference. The EMPs noted in the pool are related with the EMPs obtained with the ergometer cycle during a test of equal length ( $r = 0.68$ ). This result is probably due to the general neuro-muscular qualities of the subject since on the technical and muscular levels the efforts required are fundamentally different. The significance is actually fairly limited.

### Conclusion

An evaluation EMP test has been finalized in our laboratory and validated with 20 young swimmers 11-13 age group. The EMP is obtained by multiplying the average force by the average speed during a 6 s maximal effort.

This test seems to be relevant as a performance factor since the correlations found are  $r = 0.70$  and  $r = 0.80$ .

A good swimmer should have a high EMP and a good weight-power ratio to be efficient in sprint.

The average power is 71 w for the young swimmer whereas the relative power is  $1.8 \text{ w} \cdot \text{kg}^{-1}$ . A coach can easily evaluate this performance factor by measuring the propulsive forces with a force sensor and also by calculating the average swimming speed in a short sprint.

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# Relationship Between Freestyle Swimming Speed and Stroke Mechanics to Isokinetic Muscle Function

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## Abstract

*Maximal swimming performance is determined, at least in part, by the maximal water resistance a swimmer can overcome. Previous work has suggested that increased strength may allow the swimmer to overcome more resistance and, therefore, go faster. The purpose of the present study was to relate isokinetic muscle function to swimming speed,  $\dot{V}O_2$  max and stroke mechanics. Fifteen male university swimmers, competing in freestyle events, were studied. Isokinetic measurements of the shoulder, elbow, wrist, knee and ankle were determined, along with the maximal distance per stroke, peak speed, stroke frequency and distance per stroke at peak speed. When the swimmers were separated into high and low speed groups, there were no significant differences ( $p \leq 0.05$ ) in isokinetic strength, work or power. However, the high speed group showed differences in technical ability, as represented by an increased distance per stroke at peak speed. This suggests that other factors, such as skill of the swimmer and speed of contraction, are of more importance than muscular strength in swimming fast.*

## Introduction

Competitive swimming time for a specific distance is determined by water resistance (body drag), net mechanical efficiency and the rate of energy supply. To swim at a given speed, a propulsive force equal to the drag must be generated by the swimmer. Body drag while swimming has been shown to be highly variable and was influenced by body size, shape, density (3,19) and the distribution of mass (19). However, the two most important factors were the swimming speed and the technical ability of the swimmer (skill).

Body drag increases by a factor of 1.83 times the increase in velocity during swimming at the surface. Therefore, a small increase in velocity, over the range of velocities observed in competitive swimming, requires a large increase in propulsive force. The propulsive force in freestyle swimming is a result of both arm and leg movements, while it has been suggested that the majority of propulsion comes from the arms. This being the case, the maximal strength, power and endurance of the arm, when coupled with appropriate stroke mechanics,

would determine the maximal drag that could be overcome and, therefore, speed.

In previous studies, the maximal distance per stroke, distance per stroke at maximal speed and maximal stroke frequency have been related to maximal speed and performance time (6,8,19). These factors could be influenced by muscular strength, power and endurance. Weight training is routinely performed by swimmers; however, there is little evidence that it improves performance. In fact, increased muscle mass, particularly of the legs, could increase body density and the cost of swimming, leading to reduced performance.

This study was carried out to evaluate the relationship between isokinetic muscle strength, power and endurance determined for the arm and leg muscles, stroke mechanics and swimming speed.

## Methods

The subjects who participated in this study were 15 members of a Men's University Division II swimming team ( $20.1 \pm 0.8$  years old,  $181.3 \pm 1.3$  cm in height,

74.8 ± 5.4 Kg in weight). The subjects underwent a pre-season physical examination and completed an informed consent. Each subject participated in at least one competitive freestyle event. The swimmers were divided into high and low speed groups based on their maximal swimming speed, which was observed during the stroke frequency analysis. The 11 sprinters and 4 distance swimmers were virtually equally distributed between the high and low speed groups (5 sprinters and 2 distance in the high speed and 6 sprinters and 2 distance in the low speed group). The testing was performed immediately after the competitive swimming season, when they were in their best condition and swimming their fastest times.

Maximal oxygen consumption ( $\dot{V}O_2$ ) during tethered swimming, peak blood lactic acid concentration (La), stroke frequency analysis and isokinetic torque of the shoulder, elbow, wrist, knee and ankle were determined. Standard open circuit techniques were used to determine  $\dot{V}O_2$ . La (enzymatic) was determined 7 minutes after a maximal swim, when the peak concentration in blood was achieved and an equilibrium of La had occurred in the water compartment of highly profused tissues of the body (12). The stroke frequency analysis entailed determining the velocity of swimming over a range of stroke frequencies ( $\dot{S}$ ), from the subject's minimum to his maximum. In practice, a 10 meter distance was marked on the side of the pool, about 20 meters from the end wall. The subjects pushed off and swam through the designated area at a steady stroke rate. An observer on the deck counted the strokes and determined the time required to cover the 10 meters. This data was utilized to determine stroke frequency and velocity for each swim. The swimmer was asked to concentrate on the stroke frequency, not the velocity. Each stroke frequency vs. velocity curve was comprised of between 10-20 swims or points. The stroke frequency was increased until there

was a clear drop-off of the swimming speed. Each speed was separated by a 2-3 minute rest. The distance per stroke was calculated for all stroke frequencies. Competitive performance times were taken from the National Championship meet.

Isokinetic torque, work and power were determined using a Cybex II and upper body extension table with the CDRC computer to record the data. Three speeds at each joint and movement were used to give estimates of strength, power and endurance in accordance with the Cybex testing procedure. The apparatus was calibrated daily (Cybex Manual, Lumex, Inc., Ronkonkoma, N.Y.).

Mean ± standard deviations were calculated for all of the measured parameters for the total group and the high and low speed groups. The values for all measured parameters were compared between the high and low speed groups by an analysis of variance. To further analyze the relationship between isokinetic strength, power, endurance and swimming performance, these variables for all measured joints and movements were correlated to the peak swimming speed. Comparisons were considered significant when  $p \leq 0.05$ .

### Results

There were no significant differences between the age or height of the high and low swimming groups; however, the high speed group was ~5 Kg lighter than the low speed group. Maximal  $\dot{V}O_2$  was not significantly different between the two speed groups ( $3.83 \pm 0.36$  l/min and  $3.99 \pm 0.39$  l/min for high and low, respectively). The peak La achieved during the maximal swimming test was also not significantly different between the two speed groups ( $8.42 \pm 1.9$  mm and  $7.52 \pm 0.62$  mm for high and low, respectively). As the total metabolic power (not corrected for body weight) is important in swimming, we conclude that the high speed group did not have a

Table 1

Mean ± SD for times in seconds for competitive freestyle events from 50-150 yards and 50-1500 meters<sup>1</sup> (short course). The values are for the entire team and the fastest and slowest halves of the team.

	Sprint		Middle Distance			Distance	
	50 Y	100 Y	200 Y	500 Y	1000 Y	1650 Y	
Total	21.96	48.77	106.21	290.17	605.19	1018.04	
(n = 15)	0.47	1.81	3.27	8.96	20.94	36.72	
High	21.82	48.11	105.58	284.42	—	993.45	
(n = 7)	.47	1.41	3.14	—	—	—	
Low	22.37	50.10	107.05	292.09	605.19	1026.23	
(n = 8)	—	2.28	3.92	9.92	20.94	40.24	
	50 M	100 M	200 M	400 M		1500 M	
Total	24.38	54.14	117.90	253.91		1015.04	
(n = 15)	0.52	2.01	3.63	7.85		36.72	
High	24.22	53.40	117.19	248.87		990.45	
(n = 7)	0.52	1.57	3.49	—		—	
Low	24.83	55.61	118.83	255.58		1023.23	
(n = 8)	—	2.53	4.35	8.69		40.24	

1. Converted to meters from yards utilizing the NCAA conversion factors (21) of 1.11 for 50, 100 and 200 yds; 0.875 for 500 yds and time - 3 seconds for 1650 yds.

significantly higher metabolic power than the low speed group. Within the high and low speed groups, there did not appear to be a difference between the sprinters and distance swimmers for any of the measured parameters; however, this could not be tested for significance due to the small number of distance swimmers in both speed groups.

The results for competitive swimming times and distance are presented in Table 1. The swimming times are representative of an average Division II team. The times of the high speed group were significantly less (~3%) than the times of the low speed group at all distances.

The results of the stroke frequency analysis are presented in Figure 1. The data for the total group were similar to that previously reported for swimmers (6,19). At the point where the distance per stroke was greatest, there were no significant differences between the high speed and the low speed groups (Figure 1) for velocity, stroke frequency and distance per stroke. The peak velocity and the distance per stroke at that velocity were significantly higher for the high speed group than for the low speed group (Figure 1). This would imply a greater drag and water resistance which was overcome by a greater propulsion per stroke, as the stroke frequencies were not significantly different.

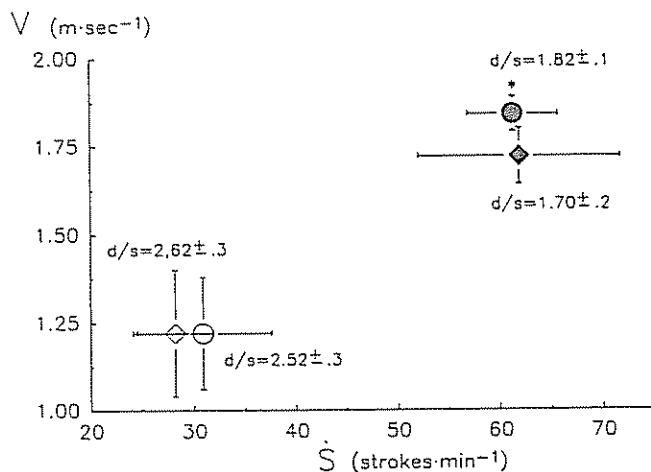


Figure 1. Mean  $\pm$  SD values of swimming velocity determined for 10 meters is plotted as a function of the stroke frequency over the same distance. The open ( $\square$ ) and open ( $\circ$ ) represent data at the stroke frequency and velocity where the maximal distance per stroke (D/S) was observed for the low and the high speed groups, respectively. The closed ( $\square$ ) and closed ( $\circ$ ) represent data at the stroke frequency and velocity where maximal velocity was observed for the low and the high speed groups, respectively. The D/S (in meters) at maximal velocity is indicated. The \* indicates a significant difference (ANOVA,  $p \leq 0.05$ ).

Data for maximal isokinetic torque for shoulder flexion, extension, internal rotation and external rotation are presented in Figure 2. Maximal strength (60 degrees $\cdot$ sec $^{-1}$ ), power (180 degrees $\cdot$ sec $^{-1}$ ) and endurance (300 degrees $\cdot$ sec $^{-1}$ ) were not significantly greater in the

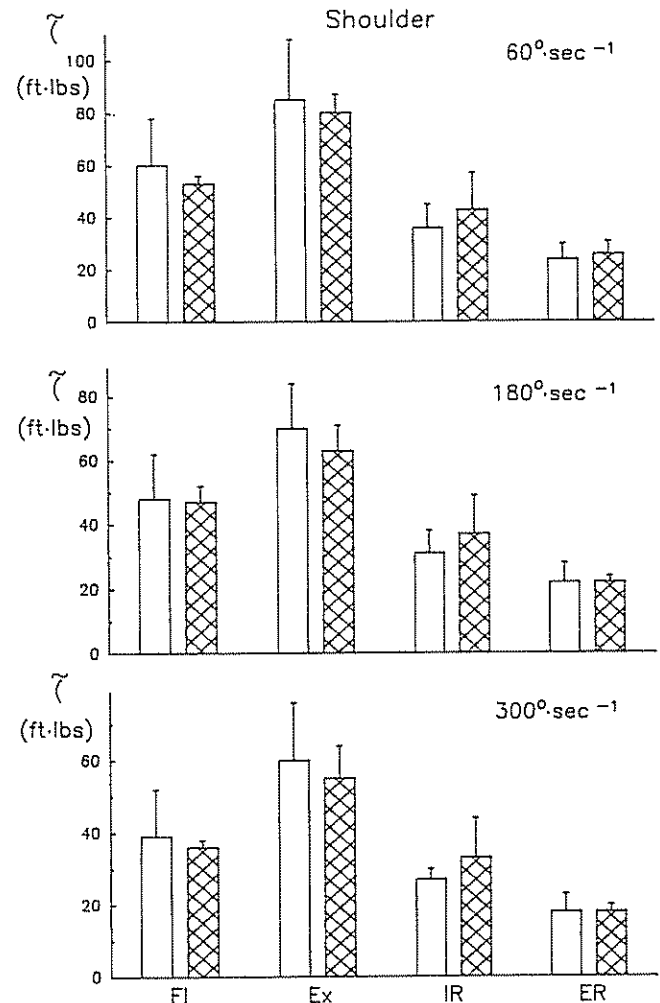


Figure 2. Mean  $\pm$  SD values of isokinetic torque for the high ( $\square$ ) and the low ( $\square$ ) speed groups are plotted for shoulder flexion (FL), extension (EX), internal rotation (IR) and external rotation (ER) at isokinetic speeds of 60, 180 and 300 degrees $\cdot$ sec $^{-1}$ . The values for the high speed group were not significantly greater than comparable values for the low speed group.

high speed group than comparable values for the low speed group for any of the measured movements.

Values for maximal isokinetic power ( $\dot{W}$ ) and work ( $W$ ) for all shoulder movements are presented in Figure 3 at contraction speeds of 180 degrees $\cdot$ sec $^{-1}$  and 300 degrees $\cdot$ sec $^{-1}$ . There were no significant differences between the high and low speed groups for  $\dot{W}$  or  $W$  during any movement at either speed.

A summary of the results of maximal isokinetic strength, torque, (60 degrees $\cdot$ sec $^{-1}$  and 30 degrees $\cdot$ sec $^{-1}$ , respectively) and power (180 degrees $\cdot$ sec $^{-1}$  and 120 degrees $\cdot$ sec $^{-1}$ ) are presented for the elbow, knee, wrist and ankle in Figure 4. The values for all measured parameters of the high speed group were not significantly greater than comparable values for the low speed group.

In general, there was a significant correlation between isokinetic torque, total work, power and endurance, as

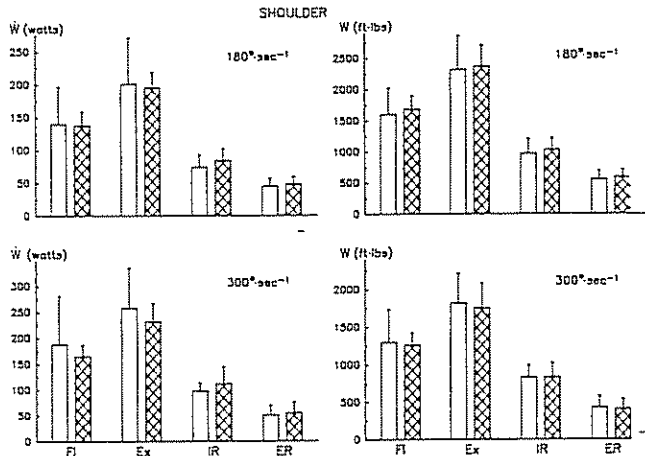


Figure 3. Mean  $\pm$  SD values for power (W, left plates) and work (W, right plates) determined during isokinetic shoulder flexion (FI), extension (Ex), internal rotation (IR) and external rotation (ER) are plotted for isokinetic speeds of 180 and 300 degrees·sec<sup>-1</sup>. The values for the high speed group ( $\square$ ) were not significantly greater than the similar values for the low speed group ( $\square$ ).

determined by a comparison of torque for the first 5 and last 5 repetitions within and between each speed (range 120 degrees·sec<sup>-1</sup> – 300 degrees·sec<sup>-1</sup>) for each joint or movement. These correlations ranged from -0.50 to 0.97. The correlations between torque, total work and power for each joint, movement, maximal speed and stroke analysis parameters were not statistically significant. There was a statistically significant correlation between the distance per stroke at maximal speed and the maximal speed ( $p \leq 0.05$ ).

**Discussion**

In swimming, a propulsive force equal to or greater than the water resistance (body drag) must be generated

by the swimmer to maintain a constant speed or to accelerate. Body drag increases as a function of swimming speed at an exponential rate (1.83), in regards to velocity. Body drag is created by the arm and leg reciprocation during freestyle swimming up to 25 Kg at 2.2 m/sec for a top level university swimmer (10,19). Less skilled or more skilled swimmers would have higher or lower drag, respectively. The propulsive force requirement would imply that muscular strength or power may be a limiting factor in swimming fast.

The propulsive force is provided by a combination of arm stroke and leg kick, although it would appear that the arm stroke is more important than the leg kick in freestyle swimming (2,4). Previous studies (6,7,8,9) have related the maximal distance per stroke and the distance per stroke at the maximal speed to the maximal velocity that could be achieved by good and outstanding swimmers. It could be postulated that the greater the strength or power of a swimmer, the greater the distance the body would travel per stroke. Therefore, the swimmer could achieve a faster swimming speed. A previous study (18) has demonstrated that the latissimus dorsi and pectoralis major are the major muscles active during the pull through phase, while the supraspinatus, infraspinatus, middle deltoid and serratus anterior were dominant during the recovery phase. The earlier muscles serve as powerful extensors during the initial pull through and assist with internal rotation. These movements are the major components of the freestyle pull. This would imply that shoulder extension and internal rotational strength should be important in determining the distance per stroke, while the other movements (like flexion and external rotation) may not. In addition, the strength and power of the legs may not be important in maximizing speed, although they definitely have a role in minimizing drag and sustaining speed.

In a previous study, swimming performance was related to dynamic peak torque as a function of age and sex (16). This study indicated that as age increased so did strength and swimming speed; however, these could be concomitants of aging and may not relate in a causal manner. In another study, a close relationship was found between power output (biokinetic swim bench) and sprint swimming performance (20). The power generated in this experiment may be related more to the maximal contraction speed than the force the muscle generates, particularly as the peak power was generated at high speeds and low resistances. The maximal propulsive force that could be generated during tethered swimming was ~13 Kg, 10 Kg and 8 Kg for swimming times of 20 sec, 60 sec and 180 sec, respectively (15). These propulsive forces are quite low when compared to the drag of swimming at high speeds, which are 15 Kg – 25 Kg (10). Studies have demonstrated increases in strength with weight training and in swimming speed with swim training; however,

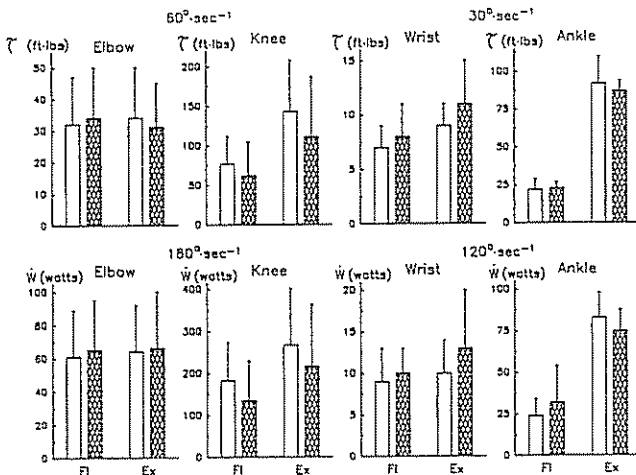


Figure 4. Mean  $\pm$  SD values for isokinetic torque and power are presented for the high ( $\square$ ) and the low ( $\square$ ) speed groups for the elbow, knee, wrist and ankle. The values for both torque and power for the high group were not significantly greater than comparable values for the low speed group.

these associations may not be causal, but coincidental (13). In a study of de-training, muscular strength was not diminished over a period of 4 weeks of reduced training; however, the ability to generate power (tethered swimming) and swimming speed were reduced (17). This would suggest a disassociation between strength and propulsive force or power, which may be related to contraction speed more than strength.

The present study was carried out to determine if swimmers on a Division II swimming team who had faster peak freestyle speed (for 10 meters) had greater muscle strength than their teammates who swam significantly slower. In addition, the relationships between isokinetic shoulder, elbow, wrist, knee and ankle strength, power and endurance and peak freestyle swimming speed were investigated. The measures of muscle function were also related to the distance per stroke that the swimmer could achieve (8). The swimmers in the present study were divided into high and low speed groups. The differences in the swimming times and peak speed of these two groups were statistically significant and would amount to finishing in the top 20, as compared to the lower 20, of the national meet. These two groups were unique in that there were no significant differences in their maximal  $\dot{V}O_2$  or the maximal lactic acid that could be achieved in the blood, after a maximal swim to exhaustion, between the high and low speed groups. Therefore, the differences must have been in the mechanical aspects of the stroke or the maximal propulsive force that could be generated for a given metabolic power.

The present study confirmed previous studies (6,8,9) that demonstrated a relationship between distance per stroke and swimming performance or maximal speed. There was a significant difference in the distance per stroke the high speed group achieved when compared to the low speed group. This was the only difference, as the stroke frequency at which they achieved peak speed was not significantly different.

The comparison of muscle function and performance was carried out utilizing an isokinetic machine. This was utilized to isolate the potential role of selected joint movements and to examine slow (strength), moderate (power) and fast (endurance) speeds. The torque, total work and power of the swimmers were greater for the shoulder and less for the knee, when compared to normal subjects or participants in other sports (Cybex). When the high and low speed swimming groups were compared, there were no significant differences in strength, power or endurance for any of the joints or movements studied. Furthermore, there were no significant differences between these parameters for the group with a greater distance per stroke when compared to the group with a shorter distance per stroke. A subsequent correlations analysis, utilizing both the high and low speed groups, did not reveal significant relationships be-

tween any of the measures of strength, power, endurance, swimming speed or distance per stroke.

This study suggests that muscular strength, power and endurance, as determined by isokinetic measurement, would not appear to be associated with swimming fast in Division II level swimmers. This must be contrasted with the high correlation seen between power and sprint speed previously reported (20). The conclusion is that the power determined on the biokinetic swim bench and isokinetic equipment are not similar. Isokinetic devices, such as the Cybex, function at speeds less than those which occur during fast swimming. At peak velocity, the stroke frequency results in an angular velocity of the shoulder greater than the 300 degrees $\cdot$ sec $^{-1}$  set by the Cybex, while the swim bench uses velocities which more resemble swimming during its power measurement. We suggest that as the swim bench emphasizes speed of muscle contraction at relatively low resistances and isokinetic testing emphasizes more forceful contractions and slow speeds, swimming fast may be more dependent upon a rapidly contracting muscle. This may be born out in the type of muscles optimum for swimming, longer with less cross sectional area. In fact, a large amount of muscle, particularly in the leg, would be counter-productive to swimming fast, as the increased density would increase the energy cost of swimming (3,19). This study emphasizes the need to minimize drag by good stroke mechanics, as high levels of propulsive force may not be productive. This was particularly evident in this population of swimmers as their metabolic powers and muscle strength were similar, while their swimming speed and performance were widely different.

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#### Acknowledgements

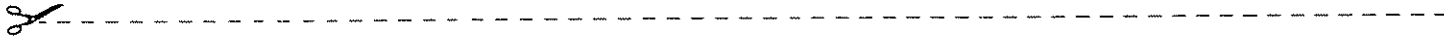
Our gratitude is extended to Don and Mary Lou Wilson for their technical assistance and to Jennifer O'Connell for preparation of the manuscript. This study was funded, in part, by a grant from the Office of Naval Research, United State Navy #N0001489C0103.



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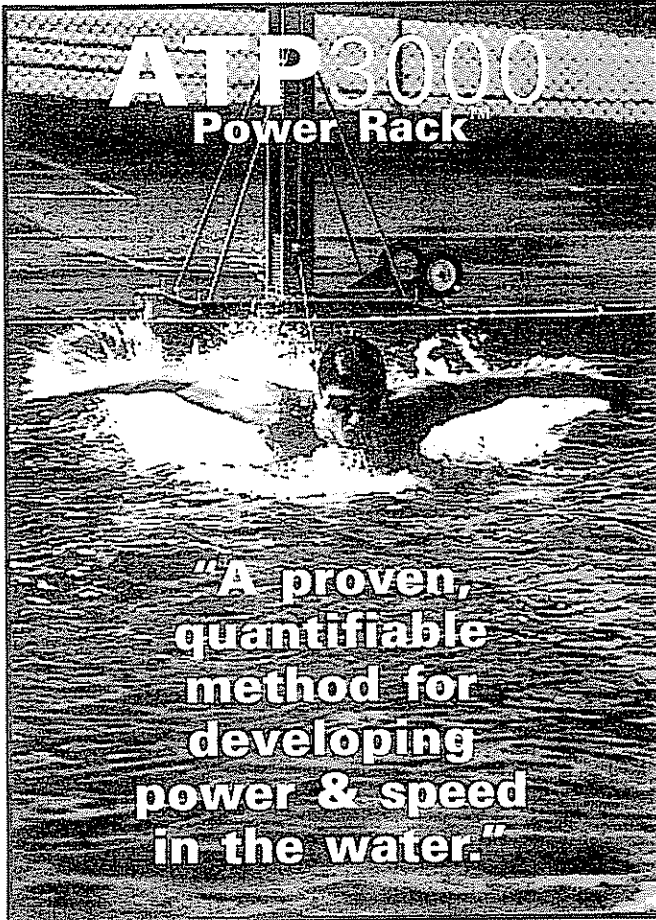
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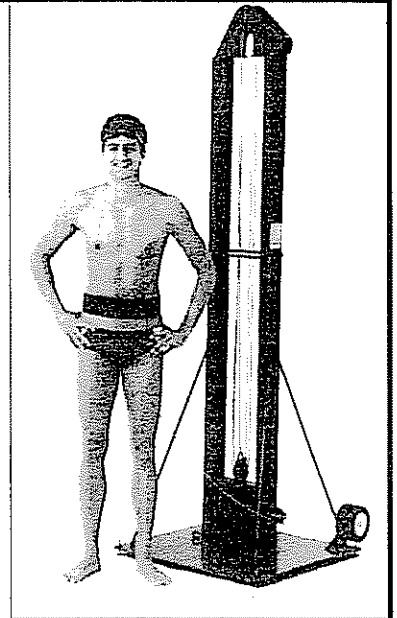


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