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

Article · October 1990

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

THE JOURNAL OF SWIMMING RESEARCH

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

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SWIMMING RESEARCH

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THE JOURNAL OF SWIMMING RESEARCH is an official publication of the American Swimming Coaches Association in cooperation with United States Swimming's Sports Medicine Committee. The American Swimming Coaches Association (ASCA) is an educational and professional service organization for swimming coaches. Its national office is located at 1 Hall of Fame Drive, Fort Lauderdale FL 33316. United States Swimming (USS) is the National Governing Body for competitive swimming in the United States. It is a Group A member of the United States Olympic Committee. Its national headquarters is located at 1750 East Boulder Street, Colorado Springs, CO 80909.

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.

POSTMASTER: Send address changes to THE JOURNAL OF SWIMMING RESEARCH, 1 Hall of Fame Drive, Fort Lauderdale FL 33316.

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

J. Swimming Research
Vol. 6, No. 3 (1990) 16-21

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 ± 0.8 years old, 181.3 ± 1.3 cm in height,

 ISSN: 0747-5993

74.8 ± 5.4 Kg in weight). The subjects underwent a preseason 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 ± 0.36 l/min and 3.99 ± 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 ± 1.9 mm and 7.52 ± 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[1] (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.

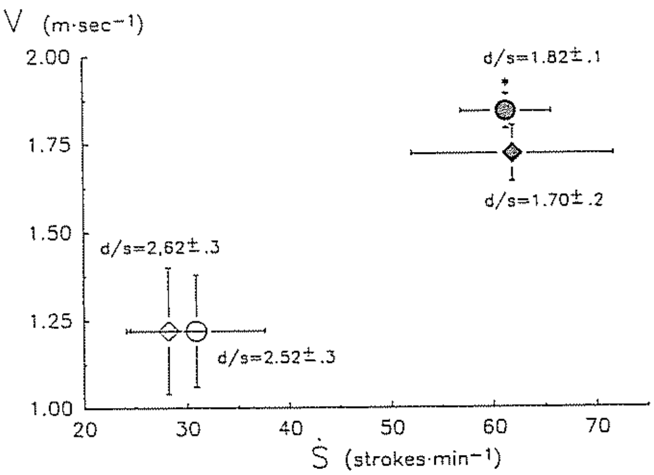

Figure 1. Mean ± SD values of swimming velocity determined for 10 meters is plotted as a function of the stroke frequency over the same distance. The open (□) and open (O) represent data at the stroke frequency and velocity where the maximal distance per stroke (D/S) was observed for the low and the high speed groups, respectively. The closed (□) and closed (O) 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 indicates. The * indicates a significant difference (ANOVA, p ⊜ 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•sec⁻¹), power (180 degrees•sec⁻¹) and endurance (300 degrees•sec⁻¹) were not significantly greater in the high speed group than comparable values for the low speed group for any of the measured movements.

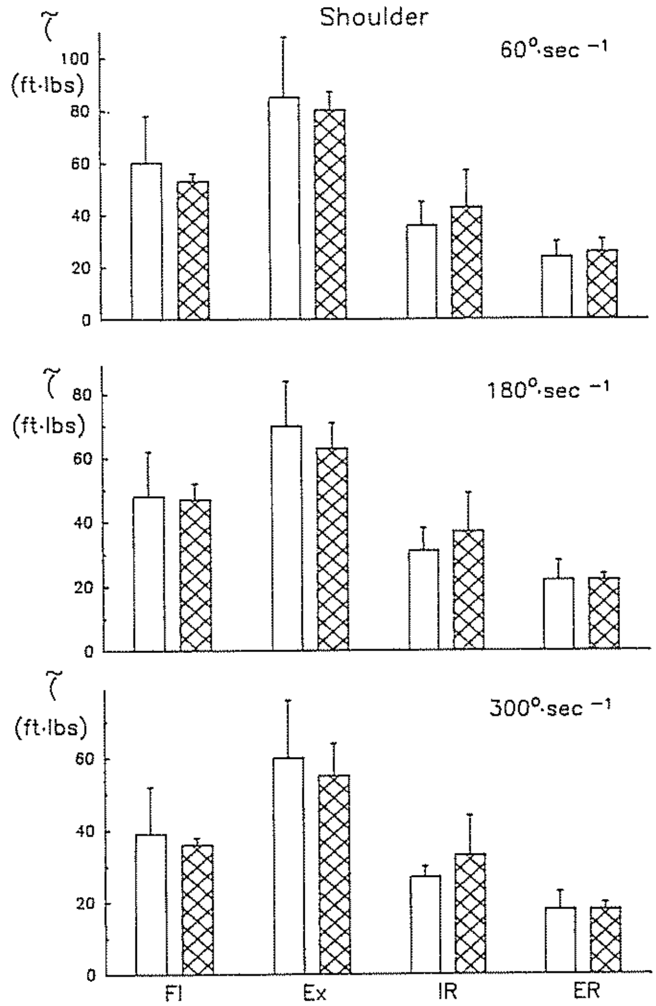

Figure 2. Mean ± SD values of isokinetic torque for the high (□) and the low (□) speed groups are plotted for shoulder flexion (FL), extension (EX), internal rotation (IR) and external rotation (ER) at isokinetic speeds of 60, 180 and 300 degrees•sec⁻¹. The values for the high speed group were not significantly greater than comparable values for the low speed group.

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

A summary of the results of maximal isokinetic strength, torque, (60 degrees•sec⁻¹ and 30 degrees•sec⁻¹, respectively) and power (180 degrees•sec⁻¹ and 120 degrees•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

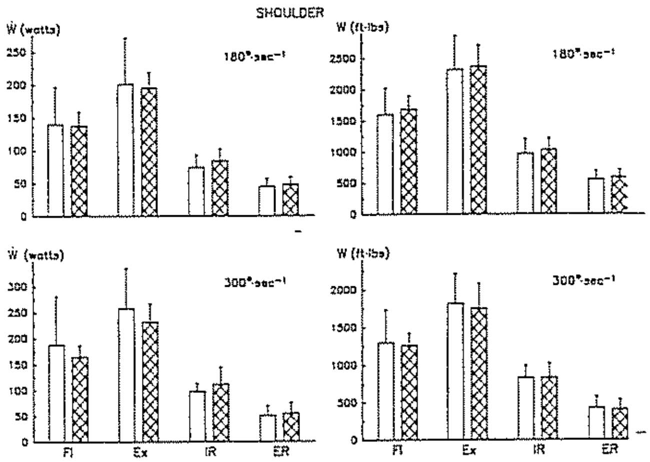

Figure 3. Mean ± SD values for power (W, left plates) and work (W, right plates) determined during isokinetic shoulder flexion (Fl), extension (Ex), internal rotation (IR) and external rotation (ER) are plotted for isokinetic speeds of 180 and 300 degrees•sec⁻¹. The values for the high speed group (□) were not significantly greater than the similar values for the low speed group (□).

determined by a comparison of torque for the first 5 and last 5 repetitions within and between each speed (range 120 degrees•sec⁻¹ – 300 degrees•sec⁻¹) 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,

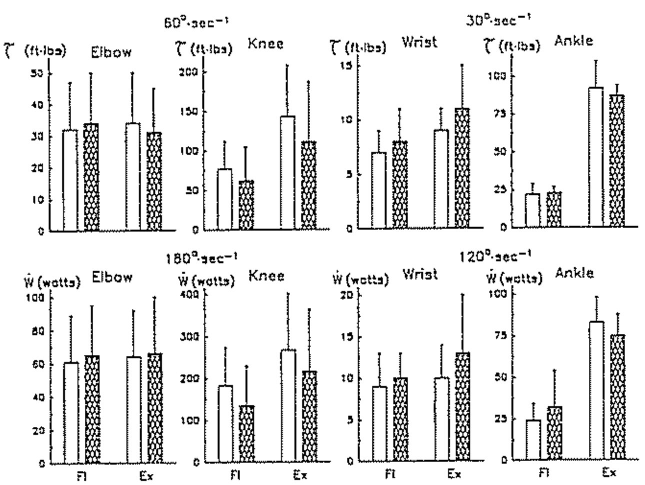

Figure 4. Mean ± SD values for isokinetic torque and power are presented for the high (□) and the low (□) speed groups for the elbow, knee, wrist and ankle. The values for both torque and power for the high group were not significantly greater than comparable values for the low speed group.

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 between 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•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 counterproductive 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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(Revised May, 1990)

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EDITORIAL STYLE. The author should submit three copies of a manuscript, typewritten and double-spaced with 1.5" margins on all edges. A short running title should be repeated at the top right corner of each page followed directly below by the page number. Authors should avoid all information which will identify human subjects.

English will be the language of this publication. As a general rule, only standardized abbreviations and symbols should be used. The first time an uncommon abbreviation appears it should be preceded by the full word or name it represents. The author is encouraged to refer to the *Publication Manual of the American Psychological Association*, 3rd edition, for editorial style concerning punctuation and abbreviations, construction of tables and figures, presentation of statistical symbols or mathematical equations, and use of standard units of measurement.

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

1. TITLE PAGE. The title page should include the manuscript title, names of author(s) and their academic degree(s), name(s) and institution(s) where work was performed, an address and telephone number for editorial correspondence concerning the manuscript.
2. ABSTRACT. The abstract (200 words or less) should summarize the study's purpose, methodology, results and conclusions. It should include a brief summary statement that provides some interpretation of the findings and their implications to the on-deck coaching and training of swimmers.
3. INDEX TERMS. A list of three or more words or short phrases not included in the title should be appended to the abstract.
4. TEXT. The text should contain separate section for the:
   a. *Introduction*. This section should state the purpose, the rationale, and the essential related literature.
   b. *Methodology*. This section should include a clear description of the experimental subjects and their controls. The description of the methodology should provide enough detail for others to duplicate the study. References should be provided for established methods and statistical procedures. Non-established methods and statistical procedures should be supported with rationale.
   c. *Findings*. The findings presented in the text, tables, and figures should follow a logical and parallel sequence. The statistical significance of appropriate results should be acknowledged.
   d. *Discussion*. This section should emphasize the study's important and original aspects while avoiding a repeat of the data presented in the findings section.
   e. *Applications*. The author should provide conclusions and possible applications suggested by their data. This section of the manuscript is of particular importance to the mission of the journal. It should be at least 500 words in length and provide in simple, laymen terms, an interpretation of the findings and implications to the on-deck coaching and training of swimmers. Where appropriate, examples of how the findings may be applied and/or how the findings may lead to further research questions are encouraged.
4. REFERENCES. The list of references should not exceed 20. They should be listed alphabetically by the last name of the author and typed double-spaced. The notation of the references in the body of the paper should be numbered in parentheses, one reference to a number. Journal articles should contain the last name of the first author, followed by initials, initials and last names of each co-author, title of article (first word only capitalized), name of journal (as abbreviated in the INDEX MEDICUS published by the Library of Congress), volume, inclusive pages, and year. An example would be: Karlsson, J., L. Nordesjo, L. Jorfeldt and B. Saltin. Muscle lactate, ATP and CP levels during exercise and after physical training in man. *J. Appl. Physiol.* 33:199-203, 1972.
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ADDRESS

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