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Swimming Economy: An Introductory Review

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Swimming Economy

The ability to maintain high intensity work is dependent on a high capacity of providing the working muscles with sufficient energy. The rate at which this energy is delivered and the efficient utilization of the available energy stores critically affects swimming performance. This can be described by the energy cost of swimming a given steady-state velocity and is properly referred to as the "aerobic demand". The ability to supply energy depends on the consumption and utilization of oxygen. The consumption of oxygen (VO2) increases proportionately with increasing velocity, from rest to maximal efforts. Clearly, one swimmer may require more oxygen to swim a given velocity than another. Therefore, that swimmer utilizing less oxygen may be considered more efficient.

The term "efficient" refers to the relationship between work done and the energy it cost to perform that work. Efficiency, however, implies a complex interaction of physiological, biochemical, anatomical, and biomechanical components all involved in the work required to move the body from one point to another. A more accurate term that describes the simple relationship of swimming velocity alone and its energy cost is "economy" (11).

The measurement of swimming economy, therefore, describes the VO2 required for a given swimming velocity and provides a useful means of comparing two or more individuals or any individual with themselves under various states of conditions. It should be noted, however, that swimming economy does not indicate what portion of the VO2 is a function of good or bad mechanics as opposed to being related to differences in metabolism that exist in different swimmers.

Historical Measurements of Economy

Early work describing the relationship between velocity and VO2 was carried out on runners (17,18,19). Only recently has the measurement of VO2 and swimming velocity been actively measured due primarily to logistical problems.

From the mid 1920's, various investigations (15,16,29, 25-28) differentiated between steady-state VO2 and VO2 while not at steady state. The cost of running at various speeds was reported and the importance of collecting VO2 at steady state was determined. During this time, various investigators (16,26) concluded that determination of the oxygen requirement of different types of effort and of different speeds and techniques of working may be valuable in a scientific study of human muscular activity. Although the importance of VO2 during submaximal exercise has been investigated for over 50 years, it has not received much attention in relation to success in, or training for, athletic performance, particularly that of swimming.

In the 1930's and 1940's, studies were actively carried out on the energy demand of exercise—mainly running—resulting in a description of differences between trained and untrained individuals (15). Robinson (26) studied champion runners and found lower lactates at a submaximal effort to be a distinguishing characteristic. This difference could be due to a higher VO2 max or better economy—either of which affects the relative intensity of the task. Efficiency and a change in efficiency have long been of concern in running as they relate with the inter- and intra-individual differences in the relationship of VO2 and running velocity (21,25,27,28). More recent studies in swimming economy have led to the same conclusions (34,35).

A closer review of the literature suggests that: A) the study of VO2 during submaximal work is worthwhile; B) there can be significant differences between and within individuals for a given velocity; C) biomechanical factors may affect the relationship of VO2 and velocity; D) fatigue affects the aerobic demand of running; and E) the relationship between VO2 and velocity is a curvilinear one.

Linearity of Measurement

Most recent studies support the concept of a linear relationship between running speed and VO2. These studies (7,10) stated that it is possible to predict VO2 from speed
of running and speed from VO2, a concept later verified by Balke (4) and refined by Daniels (12).

The concept of a linear relationship between velocity and VO2 seems to hold up during submaximal running, where the energy demands are met aerobically and where the range of running speed is rather limited. Daniels et al. (13) showed that the regression lines relating VO2 and running velocity can vary considerably among a single group of subjects, depending upon the speeds chosen for the comparison (the slope of the curve is flatter at slower speeds and becomes steeper if only higher speeds are chosen). Similar concepts have recently been verified by similar experiments with swimmers. However, this concept becomes less clear when the intensity is high and a larger portion of the energy is provided for thorough anaerobic metabolism. Therefore, quantification of energy expenditures is best evaluated when analyzing steady state aerobic exercise (in swimming, 400 meters). That blood lactic acid accumulation varies at different intensities (speeds) of swimming (32) suggests that, even though the relationship between VO2 and swimming velocity may seem linear, total energy expenditure appears to rise exponentially as a function of swimming velocity, at least beyond about 85% of VO2 max.

Effects of Age and Sex on Economy

Astrand’s (3) comprehensive study involving males and females of various ages quite clearly showed that youngsters are less economical than adults in running. Astrand explained that this lower “efficiency” prevents younger boys from running as fast as more mature boys over longer distances, even though they have equally high VO2 max’s (ml min⁻¹ kg⁻¹). This difference with age was later substantiated by Daniels and Oldridge (14) and by Daniels et al. (10) in their longitudinal study of young boys. Krahenbuhl and Pangrazi (22) found about a 28% higher VO2 submax among their young subjects, compared with adults. At the other end of the scale, Sidney and Shephard (31) have stated that older adults, as a result of loss of flexibility, are less economical than are young adults.

Though these types of studies have been carried out with running, similar comprehensive studies in swimming are not yet available. Swimming economy studies on the different age-levels found in the sport of swimming are presently underway. In light of the above mentioned running studies, it is likely that similar results will occur in swimming.

Wells et al. (36) examining differences in male-female runners found that females work at a higher percentage of their VO2 max and had equal VO2 max values, appeared equal in economy and out performed their male counterparts in a marathon. National caliber male and female runners studied by Daniels and others (13) showed no differences between the sexes in economy at three submaximal treadmill speeds. Troup et al. (34) studying elite male and female swimmers found no significant difference between these two groups at the velocities examined. This indicated that for any given speed, men and women consume the same amount of oxygen per unit body weight.

Measurement of Swimming Economy

Until recently, the majority of studies examining energy cost of swimming have used a tethered device in which the swimmer is stationary and VO2 is expressed versus increasing workload (20,32). This technique, however, is not very practical for the coach, although from a scientific viewpoint, the information is valuable. A few studies (20) have, however, examined energy cost using a swimming treadmill and have been able to express VO2 versus velocity. Still, a more practical field test needed to be developed that would allow the swimmer to move freely while reliable data could be collected, evaluated rapidly, and applied by the coach. Such a technique and protocol was developed by Daniels (11) for running and was modified by Troup and Daniels for use in swimming (33).

As discussed above, to accurately measure economy, a steady-state pace lasting around four minutes was necessary. For this purpose, a distance of 400 meters was used. The testing protocol requires the swimmer to swim a 3x400 meter freestyle effort at three or even paced velocities, usually at 1.2, 1.4, and 1.6 meters/second. During the last 100 meters of each 400 meter swim, the expired air of the swimmer is collected, using the Daniels apparatus (Figure One). Following these three efforts, a final 400 meter freestyle swim is done at a progressive pace resulting in a maximum effort during the last 100 meters of the swim, during which expired air is again collected. This testing protocol results in three submaximal efforts and one maximal effort from which VO2
among trained female and male runners respectively. Studies (34,35) on elite swimmers reveal variations of 22% and 17% among females and males. Holmer (20) first described significant differences in the cost of swimming at various velocities between recreational, competitive, and elite swimmers. Clearly, swimming economy provides an explanation for performance differences as a significant relationship between economy and performance has recently been described (35).

This point can be illustrated by the fact that one of America's more successful swimmers has one of the lowest max VO2 measured. Looking at that variable alone, one would believe that this athlete would have poor performances. However, upon close examination and evaluation of the economy curve, this athlete is most economical, which allows the individual to swim at a greater percent of VO2 max and requires a lower oxygen consumption for a given pace.

Training Implications

Data collected from swimming economy studies provides information on the type of training that is needed by the swimmer. Figure Three serves to illustrate this point. Extrapolation of this economy curve tells us what the oxygen requirements for American Record and World
Record paces. Using this technique reveals that 100 meter freestyle races require 134% of VO₂ max, 200 meters freestyle races require approximately 122% of VO₂ max, and 400 meter freestyle requires about 116% of VO₂ max. The 800 and 1500 meter freestyle races are swum at paces slightly over 100% of VO₂ max.

Analysis of this information suggests that the energy cost requires a significant contribution from the anaerobic system. Therefore, sprint type of training is required to fully develop this component in each athlete. Furthermore, training paces for aerobic adaptation, lactate tolerance training, and maximum lactate production can be prescribed. For the elite athlete, aerobic training is prescribed at a pace of 80-85% of max VO₂. This pace is also verified by finding the pace at which lactate begins to accumulate. Lactate tolerance training is prescribed at a pace of 90-95% of max VO₂, while max lactate production training requires intensities of 98-100% of max VO₂. Without doubt, the measurement and evaluation of swimming economy has great practical information that both coach and scientist can benefit from.

Summary

The economy of a swimmer is a function of inherent characteristics. These characteristics, however, are subject to some degree of alteration as a function of age, technique, sex, and level of conditioning. From an applied point of view, swimming economy can help improve training and performance. To this end, further studies are needed to better understand the types and amounts of training which affect (and improve) swimming economy. Finally, swimming economy should be considered an important variable that influences performance.

Acknowledgement

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References


In Print: Swimming 1984

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Abstract

In keeping with the original intent of the JSR, to act as a "researcher-to-coach" publication and to "educate coaches while informing them" the following bibliography has been compiled to serve the swimming community. These references have been assembled from a number of sources and although not a difficult task it was considerably labor intensive. Not all swimming related material is found within this listing. An attempt was made to include only those references judged by the authors to be information or research oriented and valuable to the swimming coach. It is hoped that this bibliography will be helpful by providing a quick and easy guide to information. If the response to this endeavor is positive it is our intent to continue these efforts in subsequent issues of JSR by assembling bibliographies for preceding and future years.

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**SPORTS MEDICINE**


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TRAINING


A Computer Based System For The Measurement of Force and Power During Front Crawl Swimming

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Abstract

In an effort to develop a test to measure swimming power in competitive swimmers, a "biokinetic" system was adapted for use during tethered swimming. The forces generated during the tethered swim test were sensed by a force transducer in the biokinetic apparatus. The voltage output from the force transducer was relayed to an A/D converter and computer (Apple II system) where tethered swimming velocity, force, work and power were calculated. This system provides a tabulated summary and graphic illustration of the swimmer's performance during the test. To demonstrate the application of this system, 76 collegiate swimmers (46 males and 30 females) were tested. Swimming power during the tethered swim was found to correlate 0.24 with biokinetic arm strength (dry land), and 0.84 with the swimmers' maximal sprint performance. Maximal swimming power for the male and female swimmers was achieved at a tether velocity of .93 and .62 m/sec, respectively. This technique offers a sensitive, and reliable method to assess muscular power in a manner that is closely related to sprint swimming performance.

Key Words: swimming velocity, work, biokinetic exercise.

Introduction

Early workers in the field of swimming research have used a variety of methods to measure the force exerted by a swimmer in the water, drag, velocity and work (1, 5, 6, 8). Recent technological advances have allowed the measurement of arm strength on land using a biokinetic bench (Isokinetic Inc., Richmond, CA). However, the ability to generate power in the water may be a better predictor of swimming speed (10). Consequently, we modified the Biokinetic apparatus to measure the power generated by the swimmer during tethered swimming (Figure 1). The system can best be described as a semi-accommodating resistance device that regulates the swimmers' velocity during the swimming stroke, provides a linear rate of acceleration with increasing forces, and allows the swimmer to move forward in the water. The system was interfaced with an Apple II computer to provide immediate results of the swimmers performance.

Figure 1. Illustration of the biokinetic apparatus and computer system used to measure velocity, force and power during tethered swimming.
sample of collegiate swimmers was low $r = .24$), suggesting that factors other than strength account for the differences in sprint swimming (4). Although the biokinetic system attempts to simulate the arm action used in swimming, the application of force against the hand-paddles differed from that employed in the water. Thus, in an effort to develop a test of swimming-specific strength and power, the biokinetic system was adapted for use during a tethered swim which allowed the swimmer to move through the water while attached to a cable. The purpose of this paper is to describe this system, and to examine the relationship between swimming performance and swimming power. Swimming performance and power values were compared before and after training in male and female collegiate swimmers.

Methods and Materials

The subjects in this research were 46 male and 30 female collegiate swimmers, who ranged in age from 17 to 22 yrs. All swimmers were tested before training (after a 6-month absence from training), and after eight weeks of strength (free-weights) and swim training (3200-8800 m/day). The mean characteristics of the swimmers before training are given in Table 1.

At each testing session the participants’ body weight, body fat (2), biokinetic strength (land), swimming power (water), and time for a 22.86 m (25 yd) front crawl sprint were measured. All tests for biokinetic arm strength were performed at a mean velocity of 2.35 ($\pm 0.06$) m/sec with a double-arm pull, as previously described by Sharp and Costill (9). Time for the 22.86 m front crawl sprint was recorded from a push-off start in the water, at the instant the swimmer’s feet broke contact with the wall until their hand touched at the opposite end of the pool. Each swimmer performed two sprints with a 3-5 min recovery between trials. Times were recorded by three independent observers, with the fastest average of the two sprints used to calculate each swimmer’s maximal sprint velocity (m/sec.)

For the measurements of swimming power, the control mechanism from a biokinetic system was adapted using 20 m of stainless steel cable (68 kg test), which was connected to the system’s recoil spool and to a harness belt. The recoil springs in the biokinetic apparatus which normally cause the hand-paddles to recoil were disengaged and a variable speed motor was attached to the ceiling shaft. This enabled the operator to engage a motor to rewind the cable after each test. During the test, the harness at the distal end of the cable was attached to the swimmer’s waist. With the biokinetic system set to release the cable at a given velocity, the swimmer attempted to swim away from the apparatus with maximal effort for a distance of 13 m (approximately 12 sec.). The force generated against the cable by the swimmer was sensed by a force transducer in the biokinetic system and converted to a proportional voltage output (0.5 volts, D.C.).

In our initial studies with this system (3, 10), the voltage output from the biokinetic apparatus was relayed to a strip chart recorder, as illustrated in Figure 2. Recently, we interfaced the output from the biokinetic system with an Apple II+ computer using an 8 bit A-D converter and timer (Rayfield Equipment, Ltd., Chicago, Ill.). The

![Figure 2. A graphic recording of the force curve during front crawl swimming. Note the difference in height of the force curves for this subject's right and left arm pulls.](image)

Table 1. Characteristics of the subjects. All measurements were made at the beginning of the study, before training. Data are presented as means ± SE.

<table>
<thead>
<tr>
<th></th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>% Fat</th>
<th>$V_{O_2}$, max(L/min)</th>
<th>Sprint Velocity (m/s)</th>
<th>Arm Strength (Watts)</th>
<th>Swim Power (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MALES</td>
<td>180.8</td>
<td>75.6</td>
<td>12.0</td>
<td>4.29</td>
<td>1.969</td>
<td>377.0</td>
<td>43.6</td>
</tr>
<tr>
<td>(N = 46)</td>
<td>± 3.1</td>
<td>± 1.4</td>
<td>± 0.8</td>
<td>± 0.10</td>
<td>± 0.021</td>
<td>± 8.8</td>
<td>± 3.3</td>
</tr>
<tr>
<td>FEMALES</td>
<td>164.5*</td>
<td>61.6*</td>
<td>21.2*</td>
<td>2.97*</td>
<td>1.738*</td>
<td>213.6*</td>
<td>25.7*</td>
</tr>
<tr>
<td>(N = 30)</td>
<td>± 2.4</td>
<td>± 1.8</td>
<td>± 0.7</td>
<td>± 0.14</td>
<td>± 0.017</td>
<td>± 8.8</td>
<td>± 1.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>174.8</td>
<td>70.9</td>
<td>15.6</td>
<td>3.77</td>
<td>1.878</td>
<td>312.5</td>
<td>36.5</td>
</tr>
<tr>
<td>(N = 76)</td>
<td>± 2.8</td>
<td>± 1.6</td>
<td>± 0.8</td>
<td>± 0.12</td>
<td>± 0.019</td>
<td>± 8.8</td>
<td>± 2.7</td>
</tr>
</tbody>
</table>

$V_{O_2}$ max was determined following a maximal 365.8 swim (3). % Fat was calculated from hydrostatic weight (1). Sprint velocity was calculated from a 22.86 m front crawl sprint. Arm strength (Mean/pull) was measured with a biokinetic system on land (6). Swim power was measured by the methods described in this paper.

*Denotes a significant difference ($P < .05$) between the means for male and female swimmers.
machine and basic language programs written for this system enables the computer to read the voltage output at a rate of 30 times per sec, and to calculate the average velocity, force, work and power for each swimming stroke or for any given time period. This program also provides a graphic illustration of the force curves throughout the "swim power" test.

The biokinetic apparatus used to measure swim power was calibrated for velocity and force using a variety of weights at each of the speed settings. The acceleration at all speed settings was linearly related to the force applied to the cable and was constant for all settings (+.014 m/sec/kg).

During the tests each swimmer was allowed two trials. The test was initiated with the swimmer in a horizontal position, 1-2 m. away from the edge of the pool. Computer measurements were initiated with the first arm stroke and terminated at the end of a predetermined period (12 sec). Swimming force, work, power, and velocity were averaged at intervals of 3 seconds.

Results and Discussion

Ten of the male swimmers were repeatedly tested at speed settings that averaged .323 (setting #1), .641 (setting #3), .954 (setting #5), 1.263 (setting #7), and 1.605 m/sec (setting #9). The mean, maximal power and force values for each of these settings are illustrated in Figure 3. As can be seen, the ability of the swimmers to generate force against the cable declined steadily with increasing velocities. It should be noted that the weaker swimmers were unable to generate any measurable force when the testing velocity was above .7 or .8 m/sec. These swimmers achieved their highest power outputs at speeds of .4-.5 m/sec. The male swimmers, for example, all attained the highest power recordings at setting 5 (.93 m/sec), whereas the females reached peak power at setting 3 (.62 m/sec). Consequently, these two groups were tested at those respective settings. The test-retest coefficient for reliability for the swim power test was .91.

Although the swimmers' (N = 76) front crawl sprint velocity correlated .84 with the swim power (Figure 4), little relationship was found between sprint velocity and biokinetic arm strength (r = .24). This low relationship between dry land, biokinetic strength and sprint performance appears to contradict earlier findings (7, 9, 10). The explanation for this discrepancy is that the subjects in the previous study exhibited a wide range of sprint velocities (1.40-2.15 m/sec) and biokinetic strength (25-490 watts), whereas the swimmers in the present study represent a more homogeneous sample. As shown in Table 1, the sprint velocities and biokinetic strength values for the present group were, on the average, significantly higher (P < .05) and did not vary as greatly as the subjects in the early study. The range in values for sprint velocity and biokinetic arm power for these swimmers was 1.71-2.21 m/sec and 128-310 watts, respectively. Thus, despite the similarities between the arm actions in the biokinetic strength test and sprint swimming, only measurements of power made in the water are specific to the propulsive forces of front crawl swimming.

As noted in Table 1, the male swimmers were significantly stronger and faster (P < .05) than the female swimmers. This difference in strength can, in part, be accounted for by the differences in fat free body weight of the males and females. When swim power was calculated in terms of power per unit of lean body weight,
the males (.656 w/kg) were still 28% higher than the females (.513 w/kg). Since similar differences were observed for biokinetic power, it is apparent that much of the difference in sprint swimming between the men and women can be attributed to a discrepancy in arm strength.

It is interesting to note that the swim power test consistently identified those swimmer’s whose greatest competitive success was achieved in either the distance or sprint events. The four fastest sprint (front crawl) swimmers (47.4 sec/91.4 m) had an average swim power of 74.5 watts (76.1-82.3 watts), compared to a mean of 41.5 watts (18.8-58.2 watts) for the four best distance swimmers (51.4 sec/91.4 m).

Measurements of swim power were made before and after eight weeks of swimming and strength training (N = 76). During that period, front crawl sprinting velocity increased 4.0% (+.08 m/sec), whereas the mean swim power increased 9.6% (+3.5 watts). Both of these changes were statistically significant (P < .05), emphasizing the contribution of specific muscle strength training to swimming performance.

An examination of the graphic recordings from the test illustrated that a large number of the swimmers had a marked difference in peak force for the right and left arm pulls. This can be seen in the asymmetry between the arm strokes for the subjects used in Figure 2.

In summary, this paper has described a technique for measuring muscular power during tethered swimming and has assessed the relationship between swimming power and sprint swimming performance. Although the resistance supplied by the tether may have imposed some alterations in the mechanics of swimming, the test was found to be sensitive to changes in muscular power and swimming performance. In light of these findings, the swimming power test should provide a sensitive and reliable method for assessing one of the components essential for success in competitive swimming.

References

The Shoulder, EMG and the Swimming Stroke

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Abstract

This article presents a review of general shoulder muscle function during movement as revealed through electromyography (EMG). Each major muscle or muscle group of the shoulder is included in this introductory review. The review reveals that some shoulder muscle movements have been defined and substantiated through EMG, however, other shoulder muscle functions have been the cause for controversy among EMG researchers because of the contradictory results reported from various studies.

EMG studies of swimming movements are limited. This article discusses data collected from previous studies using the straight pull or “push” stroke theory. Although the basic stroke has and is evolving into many forms today, the muscle functions revealed through EMG on this basic swimming pattern can be useful in injury prevention, strength and/or training programs for the swimmer.

Muscle Function as Revealed by Electromyography

Electromyography (EMG) was defined by Lenman and Ritchie (1970) as the technique which records and displays the action potentials of contracting muscle fibers and motor units. However these actions are given only for a specific muscle in isolated movement patterns. The movements performed during normal activities by the human body are complex and require varying combinations for several muscle actions. EMG becomes very valuable in this context because it allows the researcher not only to determine if a muscle is involved in a complex movement but also to what extent that muscle is involved.

EMG has also revealed that some traditional views of muscle function are not valid under various conditions. The following is a review of EMG of the shoulder muscles during various movements and with various loads applied to the upper limb.

Trapezius

EMG studies of the trapezius show that there is very little activity in static loading at the hand. This low activity was found even when the static load was increased to 25 pounds (Bearn, 1961). Wiedenbauer and Mortensen (1952) found the greatest activity in the trapezius during elevation and retraction of the shoulder and during flexion and abduction of the upper limb. According to Basmajian (1978) the trapezius is active in raising the arm and is used in preventing downward dislocation of the humerus by the upward rotation of the scapula.

Latissimus Dorsi

The powerful extensor activity of the latissimus dorsi has been confirmed through EMG studies, but the importance of the latissimus dorsi contribution to medial rotation of the humerus has been challenged (Basmajian, 1978). Reeder (1963) found EMG activity in the latissimus dorsi, when the subject was in the position, and was in arm extension, adduction and internal rotation. Activity was also noted while subjects were prone in arm lift and in internal rotation (Reeder, 1963). Basmajian (1978) states that his study the “latissimus dorsi was active during medial rotation, adduction and extension” (p. 195). Contrary to these findings, deSousa, Berzin and Berardi (1969) stated “The latissimus dorsi muscle according to our electromyographic analysis, cannot be considered as medial rotator of the arm, for, in none of the patients did this muscle reveal action potentials during both the free or resisted movement” (p. 411). It would appear that the latissimus dorsi seems to have some function in medial rotation because of the development of this muscle in athletes which have medial rotation inherent in their sport such as swimmers and baseball players.

Teres Major

The Teres major was found to have EMG activity during medial rotation, adduction and extension of the arm but only when arm movement is resisted (Basmajian, 1978). These findings were supported by Broome and Basmajian (1971), who also reported a close relationship between
the action of the teres major and the latissimus dorsi. However, Kamon (1966) found in a study of pommeled horse exercises, that the teres major was very active during the movement of the free arm after the hand released the pommel. The author theorized this activity in the following statement: "The arm returned to the pommel mainly due to gravity, but between the movements of abduction and adduction of the free arm, it was mediolaterally rotated by the teres major, positioning the hand for recatching the pommel" (p. 1917). This is in conflict with Basmajian study; however, the statement by Kamon that the arm returned to the pommel due to gravity is highly speculative. The teres major may have been contracting against the resistance of the arm weight itself instead of the arm being acted upon by gravity. The increased velocity of the arm during this exercise would also be a factor when considering resistance to movement. Lastly, Inman, Saunders and Abott (1944) imply that both the above conclusions are in error: "The muscle (teres major) never exhibits any activity during motion, but plays a peculiar role in that it only comes into action when it is necessary to maintain a static position" (p. 25). Based on EMG studies of the teres major muscle function remains unclear.

**Pectoralis Major**

According to Inman, Saunders and Abott (1944): "The pectoralis major exhibits differences in activity in the various portions of the muscle, and these in turn vary with the type of motion carried out" (p. 22). They found that the pectoralis major is not active during abduction and the clavicular head is most active during flexion. Kamon (1966) found activity during extension and medial rotation. DeSousa, Berzin, and Berardi (1969) claimed that the clavicular portion of the pectoralis was very active and the sternocostal portion minimally active during medial rotation. It has also been shown that the pectoralis major is inactive during static loading of the arm at the hand (Bearn, 1961). Generally the pectoralis major muscle was considered as adductor of the arm (Basmajian, 1978).

**Deltoid**

According to Basmajian (1978) the deltoid did not participate in medial rotation, but was active during abduction, elevation of the arm, is slightly active in flexion as well as extension and minimally active during lateral rotation. Yamshon and Bierman (1949) confirmed these findings and stated: "As the arm was moved away from the body in any direction—in forward flexion, abduction or hyperextension action potentials were recorded from all points of the deltoid" (p. 288). The deltoid also was shown to have little activity during static loading of the arm at the hand (Bearn, 1961). Furthermore, the deltoid exhibited greatest activity during abduction and between 90 and 180 degrees of elevation (Inman, Saunders, Abott, 1944).

**Supraspinous, Infraspinous, Subscapularis and Teres Minor**

The rotator cuff muscles are important muscles to arm movement. These "rotator cuff" muscles acted continuously throughout abduction and flexion. They were reported to act largely as depressors and rotators of the humerus (Inman, Saunders, Abott, 1944). Basmajian (1978) found that the activity of infraspinatus and teres minor increased linearly throughout abduction but the subscapularis reaches a peak at 90 degrees and decreases from that point on. He also states that the rotator cuff muscles act in flexion. The rotator cuff muscles were found to be inactive during the static loading of the upper limb at the hand (Bearn, 1961). However EMG activity has been found in horizontally directed muscles such as supraspinous and infraspinous (Lehmkuhl, Smith, 1983). The rotator cuff muscles function in sports seems to be that of humeral depression and rotation because these muscles, with the proper mechanics, can generate great force.

**Biceps Brachii and Triceps Brachii**

Although these muscles are not traditionally associated with the "classic" shoulder muscles they will be included in this discussion for future reference when discussing EMG during swimming movements. The biceps were active during flexion and both heads were extremely active during resisted flexion (Basmajian, 1978). Most EMG work done has confirmed the accepted muscle actions of biceps brachii. The triceps showed no action during static loading of the arm at the hand (Bearn, 1961) and was considered to act as an adductor when the arm was in abducted position (Warfel, 1974).

**Electromyography Associated with Swimming Movements**

Swimming strokes have apparently evolved rather extensively over time. The original and most widely accepted swimming method was called the push method. In this stroke movement the hand and arm were envisioned as a paddle that causes resistance against the water, thus propelling the body forward (Cooper, Glassow, 1968). Most of the EMG studies of shoulder muscle during swimming have employed this particular stroke.

The most recent theory on swimming movement is called the propeller theory. This theory proposes that "a swimmer's hands and feet can act as a set of propeller blades by changing direction and pitch throughout the stroke" (Maglischo, 1982, p. 15). Hence, each arm stroke movement can be broken down into an outsweep, down-sweep, insweep and up-sweep (Maglischo, 1982). Although this stroke pattern has been proven to be used by world class swimmers, very little EMG evidence has been gathered on this movement pattern. Therefore the follow-
ing discussion of shoulder muscle EMG during the swimming stroke relates to the push theory of arm motion.

One of the first and most extensive shoulder EMG studies done with the swimming stroke motion was undertaken by Mischio, Khachik and Mitsumasa (1964) in Japan. They compared the EMG studies of a top swimmer with that of a less skilled swimmer. Their results showed that "top swimmers use their recovery muscles (deltoid and trapezius) less vigorously and for a shorter period of time than do poorer swimmers. Good swimmers also used three of their arm depressor muscles (latissimus dorsi, teres major, triceps brachii) longer and more vigorously than did the poorer swimmers" (Counselman, 1968, p. 39). These results may partially explain why less skilled swimmers often experience shoulder "tightness or discomfort in the trapezius area and do not have adequate propulsion to achieve the speed of a skilled swimmer".

The studies which have followed this initial work of Counselman have been limited. However there is a tendency to view the latissimus dorsi as an extremely important muscle in swimming and the pectoralis major muscle as a lesser factor. Piette and Clarys (1979) stated: "The latissimus dorsi clearly has a higher mean activity than the biceps and pectoralis muscles" (p. 157). This was rather surprising because the pectoralis major traditionally has been considered an important muscle in swimming.

Vitti and Bankoff (1978) studied fifty skilled swimmers at various ages. They divided the swimming stroke into four phases: entry, pull, push and recovery. The results showed the latissimus dorsi was used extensively in the entry, pull and recovery phases but had little use in the push phase. They also found that the pectoralis major was not used extensively in any of the four phases (Vitti, Bankoff, 1978). Vitti and Bankoff (1979) did a similar study and supported the above results. They also found that latissimus dorsi was used to its greatest extent during the entry and at the strong finish of the pull and beginning of the recovery. Only slight pectoralis major muscle activity was seen at the end of the pull phase (Vitti, Bankoff, 1979). The above results were best stated in the following: "The latissimus dorsi was the muscle that participated in most of the phases of the movements and in all categories examined, with greater effectiveness, on the other hand, the pectoralis major by its sternocostal part had no effective participation in this swimming style" (Vitti, Bankoff, 1978, p. 293).

Contrary to this Ikai, Ishii and Miyashita (1964) and Piette and Clarys (1979) found that the pectoralis major muscle does participate in swimming. However, the Japanese study was done on subjects who were swimming against water resistance while the other studies were done with swimmers on inclined benches. In addition, Vitti and Bankoff (1978a, 1979b) obtained data from the sternocostal part of the pectoralis major muscle. DeSousa, Berzin and Berardi found little activity in the pectoralis major during medial rotation with most activity within the clavicular portion. The role of pectoralis major in swimming remains undecided, however, the pectoralis major appears to be used in various strokes to different extents. For example, the pectoralis major was observed as essential to the breaststroke movement during kinesiological analysis (Rodeo, 1984). In addition the butterfly and breaststroke use more medial rotation of the arms than do either of the crawl strokes. Therefore the pectoralis major may be more important in the strokes that use medial rotation.

The role of the biceps and triceps in the swimming movement was also investigated by EMG. The biceps were found to be used in breaststroke rather extensively but was not used much in front or back crawl (Maes, Clarys, Brouwer, 1975 and Jiskoot, Clarys, Lewille, 1973). Lewill (1971) found that the activity of the triceps was short and intense in breaststroke, but the period of activity was long in crawl. In fact, in a later study, Lewill (1973) reported that there was tricep activity present even during the gliding phase of the crawl stroke and observed that triceps activity during crawl was the highest observed for all strokes.

Ikai, Ishii and Miyashita (1964) found the teres major was active during the swimming stroke; the skilled swimmer was also reported to make greater use of this muscle than the unskilled (Counselman, 1968). There has been no further EMG studies done on the teres major, the rotator cuff, trapezius or the deltoid muscles during the swimming movement. Also few EMG studies were reported on the propellor theory of swimming. Hence, this is an area where further work is needed. However through EMG studies on basic movement patterns the rotator cuff muscles would appear to play an important role in the swimming movement and that the trapezius as well as the deltoid participate in the recovery phase of most strokes.

Applications and Conclusions

Knowledge of muscle contraction patterns during swimming strokes highlights those muscles that should be strengthened and which are at risk of injury. With an increased knowledge of the shoulder movement patterns, better training programs may be devised and the errors of overdevelopment could be avoided.

This overview of the shoulder also presented the debate over the function of certain shoulder muscles. For example there is a debate concerning the function of pectoralis major. Furthermore there is active disagreement over the role of teres major. Such controversy indicates that further research is needed. EMG research is also needed concerning the propellor theory of arm movement in swimming strokes.

In conclusion, the latissimus dorsi and the triceps are very important in all swimming strokes. The biceps is ac-
tive during breaststroke and less important in crawl strokes. It was inferred from other EMG studies that the rotator cuff muscles are used to some extent but to what degree has not been determined. The deltoid and trapezius are used in most stroke recovery phases. Therefore these muscles warrant specific consideration during training and development.

References

Effects of a Power Circuit Weight Training Program on Power Production and Performance

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Abstract

Seven male swimmers between the ages of 16-18 were placed on a nine week weight training program to observe changes in power production and freestyle swimming times. All swimmers had previously qualified for the Junior or Senior Nationals and had granted consent. The power weight training circuit program involved training at 30, 40, or 50 percent of their 1 repetition maximum (RM) as fast as possible for one minute followed by a 30 second rest. Swim training continued during the entire study. All measures were obtained nine weeks prior to weight training, just prior to weight training, and nine weeks post weight training. Specific power measures were obtained from the Cybex II isokinetic unit for the ankles, knees, and shoulders, and from a one minute Monark bicycle ergometer test. Functional power was obtained from the standing long jump. Swim times for the 50, 100, and 200 yard freestyle were also obtained. ANOVA with repeated measures and Tukey’s post hoc procedures were used. Significant differences (P < .05) were found between nine weeks prior to power circuit weight training, just prior to power circuit weight training, and nine weeks post power circuit weight training for the variables: ankles, knees, shoulders, and the number of revolutions performed on the bicycle ergometer. No significant differences (P > .05) existed for the standing long jump and swim times. Although the swim times for the 50, 100, and 200 yards did not show significant differences, improvements were observed. A mean difference of .75 seconds, 2.38 seconds, and 5.7 seconds respectively was observed from the period nine weeks prior to power circuit weight training and post power circuit weight training. The authors concluded that this power circuit weight training program significantly increased the swimmers power production and improved their swim times for the 50, 100, and 200 yard freestyle.

Keywords: swimmers, power circuit weight training program, performance, isokinetic exercise.

Introduction

Many factors have been shown to influence success in swimming performance. The difference between the novice swimmer and a world class swimmer is that the world class swimmer can generate greater power during a swim (13). Most research indicates that power, which is dependent on the force and the velocity of the limb
exerting this force, is the primary component in competitive swimming and that it did not seem to matter what type of strength training equipment was used to develop this power, whether it be free weights, mini-gyms, Nautilus, Universal or the swim bench (13).

Research has shown that in order to increase performance, a specific training program should be planned (3, 13, 18). In the sport of swimming this training program should consist of progressive resistance exercises which are specific to the upper and lower body and designed to develop muscular power. The particular investigations of power circuit weight training programs which would elicit optimal power production and increase performance for the sprint freestyle events have been limited. Little is known concerning the effects of a power circuit weight training program on the sprint (50, 100, and 200 yard) freestyle swimming events. It has been found that training at slow speeds isokinetically improves the power production only at slow speeds and not at faster speeds. Training at fast speeds isokinetically improves the power production not only at slow speeds but also at fast speeds (6).

Relationships between the upper body power measures to the performance of sprint freestyle swimming (25 yards or 22.86 m.) have been examined (14). They concluded that power was an essential component for success in sprint swimming and therefore felt that training programs designed to improve power were justified. The more specific the training was to the actual skill performed, the greater should be the particular improvements (10).

Another study combined running and weight training with circuit weight training (9) and found that both programs were effective in improving maximal oxygen uptake, percent body fat, and selective strength measures, but neither training program was found to be superior to the other.

The purpose of the present study was to evaluate the effects of an upper and lower body power circuit weight training program on power measures and sprint freestyle swim times. To evaluate these effects of training, Cybex II measures, standing long jump values, the number of revolutions performed during a one-minute leg ergometer test, and the performance times of the 50, 100, and 200 yard freestyle events were measured following various training sessions.

Methodology

Seven male swimmers between the ages of 16-18 who were members of an age group swimming team and who had previously qualified for either the Junior or Senior Nationals participated in the study. The physical characteristics of the group were as follows: age \( X = 16.49 + 0.81 \) years, weight \( X = 70.50 + 4.12 \) kg, height \( X = 179.34 + 5.15 \) cm, and the percentage of fat \( X = 9.22 + 4.41 \). These swimmers were involved in year round swim training of between 15,000-18,000 yards per day. The nature and purpose of the study as well as the risks involved were explained to each subject and parent prior to obtaining their voluntary consent.

The participants were pre-tested prior to any data collection in order to obtain their individual 1 RM (repetition maximum) on Universal weight training equipment.

The pre-training measures obtained included: Cybex II isokinetic values for the ankles, knees, and shoulders; a one-minute leg ergometer test; the standing long jump; and the freestyle swim times for the 50, 100, and 200 yards. All subjects came to the laboratory prior to testing in order to familiarize them with the general testing procedures and the equipment.

An isokinetic device (Cybex II Unit) which can measure the power of specific muscle groups throughout the range of motion was utilized to measure the power produced by the ankles, knees and shoulders (12).

All measures were obtained nine weeks prior to the power circuit weight training program, just prior to the power circuit weight training program, and nine weeks post power circuit weight training. Therefore, the swimmers continued their 15,000-18,000 yards swim program for nine weeks without using weights, then combined the swim program with the power weight training circuit program three days per week for nine weeks. The daily total yardage swim did not change during the 18 weeks. Various sets were used in the morning or afternoon session but the total daily yardage was always between 15,000-18,000 yards.

The stations involved in the power circuit weight training program were performed in the following order: leg extension; bench press; sit-ups with weight on chest; shoulder press; jump rope; lat pull-down; leg flexion; arm curl; bicycle ergometry; shoulder shrug; and the side bend. The power circuit weight training program required each individual to train at 30 percent of their 1 RM the first three weeks, 40 percent of their 1 RM the second three weeks, and 50 percent of their 1 RM the last three weeks. Universal Gym equipment was used for training purposes. The bicycle ergometry training session during the entire nine weeks included a workload of 450 kpm’s. Individuals pedaled maximally for one minute at this workload. Each training session included a stretching, a warm-up as well as a cool-down period. During the power circuit weight training sessions, the swimmers did as many repetitions as possible for one-minute followed by a 30 second rest in between each station. The investigators chose a one-minute training session at each station because these swimmers were considered sprinters and during competition swam events which lasted approximately one minute or less. The factors of speed and explosiveness of their motions were emphasized when lifting the weights in an effort to generate as much power.
as possible. Great care was taken by the investigators so that the correct lifting techniques were adhered to. Each swimmer performed two sets each training session. The high intensity program was diligently followed by all participants who were always motivated to improve and perform at their peak.

The 50 yard, 100 yard, and the 200 yard freestyle times were obtained during swim meet competitions. The times were recorded by the official timers of that particular competitive swim meet.

The Cybex II isokinetic dynamometer unit was utilized to obtain peak power measures for the right and left knee extension/flexion, right and left shoulder flexion/extension, and the right and left ankle plantarflexion/dorsiflexion. Measurements for knee extension/flexion were recorded while the subjects were seated with the thigh immobilized by straps. The Cybex II selector speed was set at 240 degrees per second and the ft.-lbs. scale selected was 180 (as recommended by the Cybex manufacturers). Care was taken so that the axis of rotation of the subject's knee was stabilized in line with the axis of rotation of the dynamometer's rigid adjustable level arm. Subjects were also encouraged to grasp the side chair handles for stabilization. Several warm-up contractions were permitted prior to data collection. Five maximal reciprocal contractions (extension/flexion) were performed on each leg with the peak power recorded.

The right and left shoulder flexion/extension measures were obtained on the Cybex II while the subject was lying in supine position. Subjects were stabilized with straps and the initial movement was shoulder extension. The subjects were allowed to grasp the side of the table with the non-testing hand. The selector speed was set at 240 degrees per second and the ft.-lbs. scale was 30 (as recommended by the Cybex manufacturers). Several warm-up contractions were permitted prior to data collection. Five maximal reciprocal (flexion/extension) contractions were performed on each shoulder with the peak power recorded.

The right and left ankle plantarflexion/dorsiflexion measures were also obtained on the Cybex II. The subjects were seated leaning back on their elbows with the knees flexed at 90 degrees. The initial movement was plantarflexion. The selector speed was set at 180 degrees per second and the ft.-lbs. scale was 30 (as recommended by the Cybex manufacturers). The foot was stabilized by the use of the Cybex II boot and straps. Several warm-up contractions were permitted prior to data collection. Five maximal reciprocal contractions (plantar/dorsiflexion) were performed on each ankle with the peak power recorded.

The one-minute leg ergometer test was performed on a Model 868 Monark ergometer. The protocol consisted of a three minute warm up with zero workload, then a one minute rest while seated on the bike, followed by a one minute maximal effort test at a workload of 450 kpm's. The number of revolutions performed in one minute were counted as the maximal heart rate was being monitored electrocardiographically.

The standing long jump was performed by all subjects. Several practice trials were permitted prior to data collection. The subjects were encouraged to use their arms. Three trials were given and the greatest distance recorded.

Mean values and standard deviations were calculated for each of the variables measured nine weeks prior to power circuit weight training, just prior to power circuit weight training and post power circuit weight training. The design allowed for the detection of whether this weight training program affected the power production and swim times for the 50, 100, and 200 yard freestyle. Analysis of variance with repeated measures was utilized in order to determine if the values obtained nine weeks prior to power circuit weight training, just prior to power circuit weight training, and post power circuit weight training were different. When significance was found, Tukey's hsd post hoc procedures were utilized to detect where the differences existed. In all statistical analyses, the .05 level of significance was employed.

**Findings**

The findings of the nine week power circuit weight training program for the Cybex II isokinetic measures are shown in Table 1. Measures obtained nine weeks prior to weight training, just prior to weight training, and post training were found to be significantly different (P < .05) when the plantarflexion and dorsiflexion measures were combined for the right ankle as well as the left ankle. Tukey's hsd post hoc procedures revealed that for both ankles, the post weight training values were significantly greater than the values obtained nine weeks prior to weight training and just prior to weight training but not significant between nine weeks prior and just prior.

Measures obtained nine weeks prior to weight training, just prior to weight training, and post training were found to be significantly different (P < .05) when the extension and flexion measures were combined for the right and left knees as well as the right and left shoulders. When Tukey's hsd post hoc procedures were computed for both knees and both shoulders, the post weight training values were significantly (P < .05) greater than the values obtained nine weeks prior to weight training and just prior to weight training.

The results of the nine weeks power circuit weight training program on the one minute ergometer test are shown in Table 2. Measures obtained nine weeks prior to weight training, just prior to weight training, and post training were found to be significantly different (P < .05). Tukey's hsd post hoc procedures showed that the post weight training values were significantly greater than the values obtained nine weeks prior to weight training and
Effects of a Power Circuit Weight Training Program on Power Production and Performance

Table 1. Cybex II Isokinetic Measures (Power-Watts)

<table>
<thead>
<tr>
<th>Nine Wks Prior</th>
<th>Just Prior</th>
<th>Post</th>
<th>Mean Diff. (Nine Wks. vs. Post)</th>
<th>F Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable X</td>
<td>+ SD X</td>
<td>+ SD X</td>
<td>+ SD</td>
<td></td>
</tr>
<tr>
<td>Rt Ankle Combined</td>
<td>17.21</td>
<td>16.99</td>
<td>26.71 + 43.74</td>
<td>7.93*</td>
</tr>
<tr>
<td>76.41</td>
<td>78.03</td>
<td>120.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantar + Dorsi Flex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lf Ankle Combined</td>
<td>21.98</td>
<td>16.87</td>
<td>29.56 + 44.85</td>
<td>7.64*</td>
</tr>
<tr>
<td>80.80</td>
<td>82.71</td>
<td>125.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Plantar + Dorsi Flex)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt Knee Combined</td>
<td>116.57</td>
<td>111.80</td>
<td>166.59 + 134.63</td>
<td>11.81*</td>
</tr>
<tr>
<td>601.85</td>
<td>610.77</td>
<td>736.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Ext + Flex)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lf Knee Combined</td>
<td>93.97</td>
<td>85.91</td>
<td>116.74 + 125.71</td>
<td>4.21*</td>
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<td>575.91</td>
<td>586.93</td>
<td>701.62</td>
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</tr>
<tr>
<td>(Ext + Flex)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt Shoulder</td>
<td>68.08</td>
<td>65.18</td>
<td>73.30 + 94.77</td>
<td>4.24*</td>
</tr>
<tr>
<td>332.72</td>
<td>334.99</td>
<td>427.49</td>
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<td></td>
</tr>
<tr>
<td>Combined (Ext + Flex)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lf Shoulder</td>
<td>70.55</td>
<td>53.83</td>
<td>45.37 + 92.49</td>
<td>6.46*</td>
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<tr>
<td>339.03</td>
<td>332.55</td>
<td>431.52</td>
<td></td>
<td></td>
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<tr>
<td>Combined (Ext + Flex)</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*P < .95

just prior to weight training, but not significant between nine weeks prior and just prior. Table 2 also shows that no significant difference (P > .05) existed regarding the maximum standing long jump test or the maximum heart rate values found during the one minute ergometer test.

The effects of the nine week power circuit weight training program on the 50, 100, and 200 yard freestyle times are shown in Table 3. Measures obtained nine weeks prior to weight training, just prior to weight training, and post training were not found to be significantly different. Even though the post training values showed no significant difference there was an improvement in swim times from nine weeks prior to weight training to post weight training. The 50 yard freestyle times decreased by .75 seconds, the 100 yard freestyle times decreased by 2.38 seconds, and the 200 yard freestyle times decreased by 5.70 seconds. Although not statistically significant, these times show a slight improvement following this power circuit weight training program.

Discussion

The major findings of this study were that this power circuit weight training program significantly improved the power production of the muscles which produce ankle plantar and dorsiflexion as well as knee and shoulder extension and flexion. All of these motions are intricately

Table 2. Power Tests

<table>
<thead>
<tr>
<th>Nine Wks Prior</th>
<th>Just Prior</th>
<th>Post</th>
<th>Mean Diff (Nine Wks vs Post)</th>
<th>F Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable X</td>
<td>+ SD</td>
<td>+ SD</td>
<td>+ SD</td>
<td></td>
</tr>
<tr>
<td>One Minute</td>
<td>146.83</td>
<td>167.33</td>
<td>+ 23.04</td>
<td>4.26*</td>
</tr>
<tr>
<td>Ergometer</td>
<td>144.29</td>
<td>16.95</td>
<td>+ 23.04</td>
<td></td>
</tr>
<tr>
<td>20.33</td>
<td>10.40</td>
<td>16.95</td>
<td>+ 6.53</td>
<td></td>
</tr>
<tr>
<td>Max Heart Rate</td>
<td>180.86</td>
<td>190.71</td>
<td>+ 9.85</td>
<td>1.69ns</td>
</tr>
<tr>
<td>(BPM)</td>
<td>7.06</td>
<td>7.70</td>
<td>+ .64</td>
<td></td>
</tr>
<tr>
<td>Standing Long Jump</td>
<td>88.37</td>
<td>93.58</td>
<td>+ 5.01</td>
<td>0.63ns</td>
</tr>
<tr>
<td>(Inch)</td>
<td>8.86</td>
<td>7.93</td>
<td>+ 1.07</td>
<td></td>
</tr>
</tbody>
</table>

*P < .05
Table 3. Freestyle Swimming Times (Seconds)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Nine Wks Prior X + SD</th>
<th>Just Prior X + SD</th>
<th>Post X + SD</th>
<th>Mean Diff (Nine Wks vs Post)</th>
<th>F Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Yrd. free (Sec)</td>
<td>:23.89 :02.04</td>
<td>:24.12 :00.75</td>
<td>:23.14 :01.08</td>
<td>-00.75</td>
<td>1.33ns</td>
</tr>
<tr>
<td>100 Yd. free (Sec)</td>
<td>:53.20 :06.77</td>
<td>:50.88 :09.66</td>
<td>:50.82 :05.64</td>
<td>-02.38</td>
<td>1.59ns</td>
</tr>
<tr>
<td>200 Yd. free (Sec)</td>
<td>:115.60 :06.6</td>
<td>:111.20 :03.3</td>
<td>:109.90 :03.5</td>
<td>-05.70</td>
<td>1.76ns</td>
</tr>
</tbody>
</table>

*P < .05

involved in the performance of freestyle swimming events. It must be noted, however, that all differences or improvements identified could be accounted for by the unknown, undefined effects of the additional nine weeks of training in and of themselves.

The freestyle arm pull plays a significant role in the effectiveness of the whole stroke. The arms make up 85 percent of the power production of the freestyle stroke (1). Although the power circuit weight training program did not exactly mimic the freestyle mechanics, this program did mimic the high velocity involved in the stroke performance and does suggest this program developed power as measured by the Cybex II unit in the shoulders, ankles, and knees (6).

Circuit weight training programs have shown to produce an increase in strength and have been advocated for those sports requiring high levels of strength, power, and muscular endurance (19, 20). The present study's training program goal included the specific development of upper body and lower body muscles involved in the freestyle stroke. The key to the development of power was the speed at which the lifting procedures were followed, i.e., the swimmers lifted the weights as fast as possible maintaining proper techniques. Training at fast speeds enhances the power production not only at slow speeds but also at fast speeds. The amount of muscle tension is dependent on the number of motor units recruited which ultimately affects the generation of muscular power. There seems to be a neurological adaptation which causes this increase in power production. How these neural factors contribute to improved power through training needs to be explored further (6).

The present study's power circuit weight training program also significantly improved the power produced by the swimmers on a bicycle ergometer. The training program included a station on the bicycle where the individual pedaled maximally at a workload of 450 kpm's for one minute. One minute was chosen since all of the competitive events centered around one minute. The statistically significant increase in the number of revolu-

tions was expected due to specificity of the training session, i.e., the ergometric station and the length of the training program.

Although the freestyle performance times did show a slight increase in speed for the 50, 100, and 200 yard swims statistical analysis showed them to be nonsignificant. Even though the freestyle stroke techniques were not specifically duplicated during the actual power circuit weight training program, power production was enhanced as well as the times for the 50, 100, and 200 yard freestyle. However, one should realize that even a slight improvement in a swim time over such short distances such as the 50, 100, and 200 yards is remarkable and would be extremely important to a coach and performer. These data suggest that a carry-over of high velocity training not only improved power production but the ability to improve swim performance. The practical applications are that a well trained swimmer who is swimming training distances such as 15,000-18,000 yards per day and can qualify for the Junior and Senior Nationals is able to improve their times when placed on this power circuit weight training program.

References

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