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Review: Asthma and the Benefits of Physical Activity

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Introduction

The tracheobronchial tree and lung (figure 1) have as their major function the diffusion of oxygen into the blood stream and the elimination of carbon dioxide from the blood and into the atmosphere. The lung does other jobs too. But its prime function is that of gas exchange (9). In this introduction we will focus first on the structure and function of the respiratory system, and how it is altered by asthma.

In order for gas exchange to occur the lungs require a great number of small air sacs, lined by a thin membrane, to come in close contact with a dense network of small blood vessels (capillaries) running throughout the lung. Oxygen is transported across this membrane into the pulmonary (lung) circulation where it is transported to the left side of the heart and eventually distributed to the body. Oxygen functions as the main nutrient of the musculoskeletal system, and indeed the whole body, by assisting in all cellular metabolic processes. Carbon dioxide is the by-product that is produced at the end of this metabolic cycle.

The lungs can be visualized as a tree that has been uprooted. The main trunk of the tree represents the trachea which divides into two major branches; one going to the right and the other to the left side of the chest cavity (figure 2). Multiple branches occur at this point, with each series becoming narrower, shorter and more numerous as they penetrate deeper into the lung. The terminal branches of this tree are called bronchioles, and are fine twig-like tubules which lead to small end-air passages known as alveoli.

Figure 1. The trachea - bronchial tree ends in small sacs called alveoli as depicted in A. Oxygen from the alveolus travels into the capillary and carbon dioxide moves from the capillary into the alveolus where it is expelled during expiration. Insert B.

Figure 2. The above figure shows the normal division of the tracheobronchial tree which ends in small sacs called alveoli.
This alveolated region is the site of gas exchange. There are approximately 300 million alveoli within the lung, with one capillary supplying 2-3 alveoli (9). Within the alveoli is a lubricating surface that prevents them from collapsing. However, in abnormal situations, an overstimulation of this lubrication will cause the alveolar sacs to fill up with fluid and eventually become nonfunctional.

Asthma is a disease of the air passages that is characterized by a constrictive response of the tracheobronchial tree (bronchoconstriction) to an abnormal stimulus (figure 3). Bronchoconstriction occurs in waves, or paroxysms, and leads to the classical symptoms of shortness of breath (dyspnea), cough, and a whistling sound known as wheezing, which are the trademarks of an asthmatic individual.

Typically, most attacks are short-lived, however, a long phase of spasms and wheezing may occur during certain times of the year. Generally, an asthmatic patient will experience some degree of symptomatology, secondary to airway narrowing, on a daily basis. Although symptoms usually respond to medical therapy and allow individuals to carry out normal activities, severe bronchospasm may lead to an emergency situation which requires immediate medical attention.

The purpose of this review is to introduce swimmers and coaches to the principles behind asthma and to address the methods whereby asthmatic individuals can benefit from swim training. This review will also focus on some of the more common drugs that are used in the treatment of asthma. It is felt that coaches and swimmers should have some knowledge of asthmatic drugs since they have certain side effects that can decrease performance, and/or may be considered by the United States Olympic Committee and the Federation of International Athletics as banned substances.

**PREVALENCE AND ETIOLOGY OF ASTHMA**

It is estimated that approximately 2% of the world population has some element of asthma (9). The disease may begin at any age, but more frequently affects males at a ratio of 2:1 (9).

The abnormalities in an airway during an asthmatic attack can include small muscle spasm with bronchiole constriction, mucous plugging of the airways, or swelling of the lining of the tracheobronchial tree (9). The end result is a narrow airway which produces a sound called wheezing, and if the disease is longstanding, will eventually lead to destruction of the air sacs of the alveoli and resemble a condition known as emphysema. In its earliest stages pulmonary function studies may be the only means of diagnosing an asthmatic condition.

**Etiology**

There are three major classifications of asthma: allergic (extrinsic), non-allergic (intrinsic), and a new classification termed exercise-induced asthma (EIA). These three classifications will be discussed in the following paragraphs.

Allergic asthmatics have a high sensitivity to substances in the environment that typically create narrowing of the airway and result in bronchospasm. It frequently affects younger age groups and often these individuals outgrow their allergic reactions. This form of asthma is often associated with a family history of allergies such as rhinitis (runny nose), urticaria (itching), and eczema (9). Skin tests may reveal the airborne substances that precipitate these attacks and frequently the allergic individual can have desensitization to the allergen. Seasonal variations will lead to fluctuations in the severity of attacks. There are also nonseasonal allergens such as feathers, animal danders, or molds, which present a constant irritation to the allergic asthmatic and can cause symptomatology all year long.

In non-allergic, or intrinsic, asthma there seems to be an abnormality within the lung and a strong family history of asthma. These individuals may also have an allergic component. Those individuals afflicted with intrinsic asthma frequently have airway difficulties throughout the year, and it is unlikely that they will outgrow the symptoms once they have developed. These children, therefore, must be prepared to accept and treat their disease with medication, and avoid any activity that precipitates the problem, for the rest of their lives.
Exercise induced asthma (EIA) is an entity that is thought to be due to the cooling effect in the lungs that is produced when water is evaporated from the lung surface. An EIA Attack can be precipitated, or induced, by such exercises as running, cycling, jumping, or weight-lifting. Susceptible individuals are thought to have altered humidification processes in their lungs. Symptoms are induced by breathing large volumes of air with a low water vapor content. It is this latter phenomenon that makes swimming the most beneficial physical activity for those suffering from EIA; since a swimmer, breathing just a few inches from the water surface, is inspiring very humid air and decreasing the risk of an asthmatic attack (1).

Symptoms

One of the main reasons for coaches to be able to identify the beginning of an asthmatic attack is that in its early stages even short bouts of bronchospasm can lead to lowering of blood oxygen levels. If detected early enough it is possible to reverse the process, through appropriate treatment, and continue with the activity. It is only in its severest form that asthma creates a sharp drop in the blood oxygen level and carbon dioxide accumulation.

The signs that are most often associated with an asthmatic attack include: tachycardia (rapid heart rate), sweating, and short, rapid respirations exceeding 40-50 breaths/minute. Obviously, these clinical signs are also evident during strenuous physical activity and, therefore, the swimmer must be able to recognize those subtle changes in breathing pattern which may be an imminent sign of an asthmatic attack. It is also important for coaches and parents of asthmatic children to be aware of these signs and symptoms so that when recognized and treated appropriately the swimmer can continue the workout.

As mentioned earlier, the three classical signs of an asthmatic attack are dyspnea, cough, and wheezing. While wheezing is often regarded as the only single sign of an impending attack, typically these wheezing bouts are episodic, often occurring at night and during certain seasons of the year. The first sign to recognize is the cough, usually dry and without production of sputum, and frequently followed by a feeling of breathlessness. The breathing pattern then becomes rapid and audibly harsh, and wheezes can be heard during both inspiration and expiration. Wheezing is the end stage of an attack and, if possible, the asthmatic child should be treated prior to its onset.

Medical Treatment

The object of medical treatment of the asthmatic is to halt an attack before severe wheezing and a drop in oxygen in the blood can occur. Medical treatment with inhalation substances (breathalyzers) are usually effective in the acute asthmatic attack; whereas pill and liquid forms of drugs are more long-acting, prevent inflammation, and decrease the number of asthmatic attacks.

It is common for asthmatic athletes to have with them a breathalyzer to halt an acute attack when they are experiencing early signs of bronchospasm. Coaches should encourage their swimmers to utilize these substances during workouts any time they are experiencing shortness of breath, dry cough, or wheezing, since early treatment may allow them to continue at a somewhat less vigorous workout. Hospitalization is rarely required in these situations unless the attack lasts for an extended period of time and does not respond to either the cessation of the activity or to the use of the drugs.

A detailed description of drugs will not be included in this treatise. However, in the following sections you will find a partial list of generic drugs currently in use in the treatment of asthma, along with their more common side effects.

Medication

Terbutaline (Brethine) is a stimulant of receptors in the bronchioles that causes bronchodilation. It has few side effects on the heart and is an excellent drug for preventing asthmatic attacks from occurring. It does not, however, have any benefits during acute asthmatic events. It therefore needs to be used on a daily basis.

Theophylline and Aminophylline preparations belong to a classification of drugs known as the methylxanthines. These preparations come in both pill and liquid form as well as in an aerosol and can be used in the prevention of an acute asthmatic attack, as well as be taken prophylactically. Like all drugs that stimulate the central nervous system, their side effects include irritability, occasional agitation, insomnia, tachycardia, and palpitations. These drugs should therefore be taken cautiously (12).

For the treatment of children with allergic bronchospasm, as well as for those suffering from EIA, cromalyn sodium has been very effective in preventing asthmatic attacks from occurring. It has no side effects on the heart, and no benefit to the individual experiencing an acute asthmatic event. It takes several weeks to be effective and must be taken on a regular basis.

A new synthetic steroid, Bectonethasone (Vancelii) provides an effective method of delivering topical steroids through an inhaler while decreasing the inflammation of the lungs. This drug is acceptable during competition since it has no significant side effects on the heart or on the neuromuscular system. It cannot be used for acute asthmatic attacks and is only beneficial
when taken on a regular basis. Vanceril is an excellent alternative drug in the treatment of asthmatics who require steroid therapy intermittently.

The final classification of drugs are those known as the corticosteroids which have a very effective role in the treatment of chronic, long-standing asthmatic attacks. This classification of drugs is especially beneficial in the severe asthmatic attack that requires hospitalization, or when a short-term drug therapy is necessary in decreasing the number of asthmatic events. Corticosteroids are commonly used in an emergency asthmatic situation, but their long-standing side effects prevent their use during competition because of the effects on the neuromuscular system.

Side Effects

The side effects of the medications used in the treatment of asthma are often difficult to discern from an actual asthmatic attack or strenuous exercise. The most common side effects are tachycardia, pounding of the heart (palpitations), dizziness, high blood pressure, and occasional irregularities of the heart beat. For this reason it is helpful for coaches to discuss the treatment of their asthmatic swimmers with the team physician so that he may assist in determining those drugs which would be best in preventing side effects. It is also important for the coach to be able to recognize the symptoms of drug overdose in their athletes. Early signs of overdose can include: increased anxiety, agitation, hyperexcitability, and headache. These too can be symptoms of an approaching asthmatic attack, so it would benefit the coach to know the history of his asthmatic swimmer and what signs to look for.

Psychotherapy

While medical therapy is the hallmark of the treatment of asthmatic attacks, it is also possible to incorporate other forms of mind control in decreasing the incidence of bronchospasm. A great deal of work has recently been done in the area of sports psychology, self-hypnosis, and imagery, whereby the psychological component of bronchospasm can be better controlled (7,8). It is worth investigating for the asthmatic to begin to identify what portion of his or her symptomatology may be controlled with better understanding of the subconscious stimulus to bronchospasm. For the benefit of the asthmatics who are swimmers, it appears that some form of behavior modification such as biofeedback, self-hypnosis, or imagery, may be extremely beneficial as an additive form of therapy in the treatment of bronchospasm.

Banned Substances

Many of the drugs that are used in the treatment of asthma (both prescription and over the counter) contain chemicals that are considered illegal by international sporting regulations. These substances have been banned because of their stimulant or depressant qualities on either the neural or muscular system, and can be detected by sophisticated urine and blood tests that were developed for the USOC and FINA sporting events.

One that has received the most publicity are those belonging to the category known as the anabolic steroids or male hormone classification. There are numerous other drugs which are used for allergic reactions as well as asthma which have been limited by the USOC. It is important for all athletes, coaches, and physicians to ask the USOC sports medical clinical staff for direction and current assistance on respective medications of interest to them (6).

It must be understood that even though a substance on the IOC’s banned list is prescribed by a physician or dentist for a currently justified purpose, it remains a banned substance in sports. Use of anti-asthma drugs such as Proventil or Brethine are permitted only if the USOC physician attests prior to the athlete’s competition that it was clinically justifiable and necessary for the health of the athlete. Dosage, history of using, and time of administration must be provided on paper to the IOC doping control commission to prevent disqualification of this athlete. Prior to international competition it is always advisable to check with the USOC team physician or the USOC drug control hotline (1-800-233-0393) before using any medications not listed below (17).

When medically necessary, special consideration is given for certain anesthetics, corticosteroids, beta blockers, and occasionally diuretics. For an asthmatic, cromalyn sodium and terbutaline is approved if the team doctor notifies the chairman of the IOC medical commission beforehand which athletes on his team are asthmatic and are using or may require the use of these drugs. The medical commission has also decided that the use of corticosteroids must be declared on the occasion of the competition. Any doctor using corticosteroids must state the country; the name of the competitor being treated; the name, dose, and route of administration of the drug; the reason for this use; and date of administration. All of this must be signed by the physician (17). If FINA or the USOC has been notified prior to competition of the medications that have been chronically used in the treatment of the asthmatic individual, it is highly unlikely that they would be banned for use during the competition.

It is also important to realize that even simple substances such as caffeine, found in over the counter drugs used for sinus problems and decongestants, are banned by the USOC and they too must be justified by a physician. Since caffeine is a stimulant of the
central nervous system and may enhance athletic performance, the athlete and coach should be prepared to switch to another form of decongestant if their request for continued use of this medication is denied. Other drugs that stimulate the central nervous system and are used for asthma, allergy, colds, sinus infections; such as Actifed, phenylephrine, Bronkaid, etc., may also contain substances that are banned by the USOC.

Review of the Literature

There is a considerable difference of opinion amongst health care professionals as to the benefit of breathing exercises and medications to use in the treatment of asthmatic children. A study done in 1983 in the British Medical Journal indicated that pediatricians and consulting physicians revealed a disturbing difference of opinion as to whether or not exercise helps children outgrow asthma. (11). The results clearly make it more difficult for both parents and coaches to get advice as to whether exercise benefits the asthmatic child.

Recent studies that have evaluated the effects of an exercise program for children and adolescents suffering from asthma have indicated that lung functions will deteriorate in the beginning of the exercise (2,15); making it necessary, at times, to use medication prophylactically at the onset of a workout, along with a modification of the exercise. Other research has found, however, that exercise and/or training will improve an asthmatic's aerobic endurance and decrease the number of asthmatic attacks. (10,14).

To evaluate the benefit of swimming to other forms of exercise, Inbar (13) compared the lung functions of asthmatic children while exercising on a treadmill to that achieved during a tentered swimming exercise in a humid environment (80-90% saturation). Their results indicated that the lung functions of the asthmatic children decreased more markedly following the treadmill exercise than they did following swimming. These results suggest that the type of exercise may influence the severity of EIA. Swimming may have a clear benefit over other forms of physical activity because of the relatively high humidity content in the air that is encountered while swimming. When these same children were exercised on the treadmill in a more humid environment, their lung functions showed less of a reduction.

Exercise induced asthma, as mentioned earlier in this review, is an entity that is thought to be due to the cooling effect on the lungs produced when water is evaporated from the lung surface. Susceptible individuals are thought to have altered humidification processes in their lungs. Symptoms are induced by breathing large volumes of air with a low water content. Evidence suggests that EIA is precipitated by running and cycling, but is often less severe while swimming (2).

Regardless of the form of exercise, however, the growth of recent information indicates that exercise is of benefit to those suffering from asthma (13). When proper medication is used in conjunction with a modification of the training program, exercise has been shown to effectively increase the aerobic capacity of the individual while decreasing resting heart rate and the number of bouts of bronchospasm. Of equal importance is the subjective feeling of well-being on the part of the asthmatic individual following exercise and training.

How Should Coaches Approach Asthmatic Swimmers?

The way a coach and/or teammate reacts to an asthmatic swimmer may be just as important to the swimmer's performance as the asthma attack itself. Coaches armed with proper knowledge of the individual's problems, identification of the source of irritants, and willingness to alter training programs to suit the individual's needs, has led to world class performance despite the limitations of asthma.

One of the problems facing these swimmers is often the misunderstanding that results when teammates are not aware of the problems associated with asthma. When they are informed of the need for prophylactic measures, resentment and accusations that arise when an asthmatic swimmer is continually excused from a certain swim set or weight training routine can be avoided.

If a swimmer has only mild discomfort and wants to continue but cannot keep up with the rest of the team, it is perhaps possible to keep him active in practice by changing the intensity of the set or allowing a lower intensity pulling or kicking drill. A kicking set may be preferred due to the fact that a strict breathing pattern does not have to be maintained.

Since the mechanism behind asthmatic attacks may have something to do with the cooling effect on the lungs when water is evaporated, there are certain activities; i.e., running indoors, running stairs, jumping rope, etc., that may stir up certain dust particles and precipitate a deterioration in breathing functions in asthmatic individuals. Many teams have weight rooms where mold, dust, or damp areas may create a problem for the asthmatic. If the problems can't be corrected, it may be necessary to eliminate that particular setting as part of the athlete's training program.

Swimmers may also be sensitive to certain pollens, so that recent mowing of the lawn, a change in chlorination of the pool, fumigation with insecticides, tobacco smoke, and other irritants may precipitate an attack. Alternative training programs are therefore necessary, and this places the coach in a position of
designing innovative training programs that eliminate many of the asthmatic events.

Since weight training may be an integral part of the swimmer's workout, it may be necessary for him to carry out his weight training program in a different weight room where allergens are reduced to a minimum. Such a setting may be a home weight room, a health facility that has Universal and Nautilus equipment where the environment is fully controlled from a temperature point of view and has less dust and mold in the area. Alternative means of training swimmers' upper bodies may include the use of hand paddles during many of the drills, or the use of hand-held weights, such as Heavyhands, which can help develop upper body strengths when weight rooms create asthmatic attacks. There seem to be clear benefit to the swim bench, and now a new machine called the Cybex Upper Body Ergometer (UBE), that may be beneficial as an alternative means of improving upper body strength in those asthmatic swimmers suffering from bronchospasm secondary to dust, molds, and other activities.

Proper nutrition with complex carbohydrates (representing 70-80% of the daily caloric intake) and moderate protein intake of 15-20% are also important aspects to consider for the asthmatic child. An increase in hydration is also important to decrease the drying effect that occurs. Despite the fact that swimmers are not often asked to consume excessive quantities of water during workouts, it may be a simple means to force fluids on these athletes to prevent the drying effect that occurs during athletic activities and increase the performance achieved at high humidity environments.

Summary

Patient and family education, avoidance of smoking and other inhaled irritants, avoidance of infection, adequate water intake, minimum stress environment, and proper nutrition, are all important parts of allowing asthmatic athletes to perform to their highest potential. While physicians are not all in agreement as to the benefits of physical activity, the evidence clearly indicates both subjectively and objectively that physical training benefits individuals with asthma. There seems to be a reduction in severity of their attacks, a decrease in the number of medications required to control their attacks, improved compliance, reduced number of school days lost, and an increase in exercise activity and aerobic capacity. The exercising asthmatic individual has fewer number of days and bouts of wheezing, and requires fewer hospitalizations than the non-exercising individual. Since there seems to be emotional distress associated with asthma, self-help education and exercise programs considerably reduce the debilitation from the disease as well as improve the interpersonal relationship between child, parent, and coach.

Swimming seems to have an added benefit in treating not only intrinsic and extrinsic asthmatics but also for those with EIA where running and cycling in a low humidity environment may often precipitate bronchoconstriction. The swimming coach, therefore, needs to be knowledgeable about allergic diseases and asthma, and somewhat knowledgeable about medications and willing to alter workouts since excellent athletes may be prevented from high performances because of rigid training schedules.

Typical changes in temperature where cold air, dust, pollen, molds and air pollution may precipitate asthmatic attacks should be carefully evaluated by the coach when one of his swimmers with asthma begins to deteriorate during workout. It is often necessary to use a certain degree of imagination when a certain activity is known to precipitate an attack.

It is necessary to recognize that the earliest symptom of an asthmatic attack may simply be tightness in the chest, followed by a cough, shortness of breath, and finally, wheezing. If this is recognized early, the swimmer may be treated and allowed to continue their workout without any risk to the coach or individual. However, it is mandatory that once wheezing occurs, the workout be limited or stopped until the symptomatology is completely, or nearly completely, relieved.

Those alterations in training programs should be used by coaches and shared with coaches and swimmers around the country so that talented swimmers can function to their highest potential. Medical professionals also need to be aware and willing to work with the team as well as with the team physician in the rehabilitation of those people not only suffering from asthma and other allergic disorders, but also with those suffering from chronic obstructive lung diseases of other types. I hope that this article will instill in all of you the imagination necessary to foster an athlete who is somewhat limited by a minor lung ailment but who may certainly maximize his performance and become an outstanding performer in swimming.

References

Serum CPK Levels in Male and Female World Class Swimmers During a Season of Training

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Dept. of Renal Medicine,
Shands Hospital, Gainesville, Fla.,
and Dept. of Athletics,
University of Florida, Gainesville, Fla.

Abstract

The effect of a season's training on serum creatine phosphokinase levels (CPK) was examined in 10 male and 10 female elite swimmers from the University of Florida. During each of five months, a venous blood sample was drawn immediately following a swim workout and then approximately 45 hrs later prior to a swim workout to determine serum CPK. Weight training and swimming training increased from Month 1 through 4 (5,000 to 12,000 yds/day). During Month 5 (the taper prior to NCAA Championships), the quantity of swimming yardage was reduced (4,000 yds/day) and emphasized quality training. Mean post-exercise CPK levels in males and females decreased from Month 1 (267.9 ± 47.7 I.U./L and 165.10 ± 37.2 I.U./L) through Month 4 (171.6 ± 26.4 and 88.50 ± 7.6 I.U./L), and 62.8 ± 5.5 I.U./L). Resting CPK values for males were significantly higher than females during Months 1 and 4, but not different in Months 2, 3, and 5. These higher CPK values in males were not related to their greater lean body mass. It was concluded that swim training increases serum CPK more in males than in females except during the taper prior to the national championships. The stress of training as indicated by elevated CPK levels is greatest early in the season for both males and females. Periodic measurement of CPK in swimmers during the season along with other physiological indicators might aid in the assessment of overtraining in swimmers.

Introduction

The muscle enzyme creatine phosphokinase (CPK) is increased in the serum following strenuous, endurance exercise (13, 14), and short-duration maximal exercise (4, 5). Various reasons for the increase in the blood have been reported; including duration and intensity of exercise, type of activity, and fitness level of the individual. It is not clear which of these factors is more important in causing CPK efflux into the blood. In addition, the physiological mechanism responsible for increased serum CPK has also been clearly established.

Many studies have investigated the acute response of males after a distance running event (8, 9, 14). However, few have examined CPK response over the course of a training season. Also, studies which have investigated highly-trained swimmers are limited. Only one study to date has investigated CPK levels during a season of swimming training (2). Burke (2) found a 60% increase in CPK from early November to January (heavy training period). During the taper phase (March), CPK levels decreased but remained in the high-normal range. The authors concluded that intense training elevates CPK and so might serve as a sensitive index of the adaptation to exercise stress.

To our knowledge, no published research exists investigating serum CPK levels in highly-trained women during a season of swim training. The purpose of the present investigation was to compare the resting and post-exercise CPK levels of the elite male and female collegiate swimmers during five months of training.

Methodology

Subjects

The subjects were ten male (mean age 19.9 ± .7 yrs, weight 80.9 ± 4.7 kg, and body fat 6.6 ± 1.2%) and
ten female (mean age 18.7 ± 4.7 yrs, weight 62.6 ±
4.8 kg, and body fat 18.3 ± 1.2%) swimmers from
the University of Florida, Gainesville, Florida. All sub-
jects had been finalists in the National US Swimming
Championships or National Collegiate Athletic Asso-
ciation Championships. Both the women's and men's
teams won the Southeastern conference meet and placed
in the top five in the NCAA meet. All subjects gave
written informed consent prior to participation in the study.

Swim Training

The months of the training season studied were Oc-
tober (Month 1) through March (Month 5) prior to the
NCAA Swimming Championships. All subjects were
involved in a swimming and weight training program
directed by their coach (table 1). The swim training
consisted of traditional lap swimming and sets of teth-
ered swimming. Weight training exercises were per-
formed Monday through Thursday afternoons each
month except during Month 5. Both males and females
performed similar training workouts. The intensity and
duration of training were increased progressively from
Month 1 through Month 4, after which the quantity of
training decreased dramatically during the taper period
prior to the National championships in Month 5 (Table
1). During the taper phase there was a greater propor-
tion of race pace swimming than earlier in the season,
with a decrease in total swimming yardage. The pur-
pose of the taper was to allow swimmers to recover
from the previous months of intense training.

Body Composition

Body density was estimated by skinfolds according
to the equations of Sloan and Weir (15) during each
month of training. This procedure utilizes 2 skinfold
sites: triceps and suprailliac for women, and thigh and
subscapular for men. The percentage of body fat was
computed using the equation of Brozek et al. (1).

Blood Sampling

Blood samples were obtained from an antecubital
vein twice each month during the season, on a Sat-
urday morning after practice and on the following Mon-
day morning prior to practice. The swimmers did not
exercise vigorously for approximately 48 hours between
the post-exercise and resting blood sample.

All samples were subsequently centrifuged and serum
CPK assayed spectrophotometrically by Smith Kline
Laboratories using an enzymatic method. The normal
range for values was considered to be 80-120 I.U./L
using this procedure.

Statistical Procedures

A two-factor (gender × time) analysis of variance
with repeated measures on the second factor was used
for comparison between male and female CPK values
at rest and post-exercise over the 5 months. The least
squares means procedure determined where significant
differences occurred. A Pearson product moment cor-
relation coefficient was used to determine the strength
of the relationship between fat-free weight and CPK
post-exercise values. An alpha level of 0.05 was used
for all significant tests.

Results

Significant differences were found between male and
female mean post-exercise CPK values. The mean post-

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Intensity of Training</th>
</tr>
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<tr>
<td>Number of Swimming Work-outs per Week</td>
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<td>Duration of Swimming Work-outs (in min)</td>
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<tr>
<td>Avg. Daily Distance (Yds. × 1,000)</td>
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<tr>
<td>1. Sprint</td>
<td>5-6</td>
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<td>Avg. Lbs. of Wt. Lifted</td>
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<td>1. Leg Press</td>
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*Higher repetitions performed by distance swimmers, middle number by mid-distance, lower by sprinters.
exercise CPK values were significantly higher ($p<0.05$) in males than in females during Months 1 through 4 (Figure 1). The values for females during these months were 30% to 48% lower than the males. However, during Month 5, the difference between sexes in post-exercise CPK was not significant, females having a value only 3% lower than males.

Significant differences were found between male and female resting CPK values (Figure 2). The mean resting CPK level in females was significantly lower during Months 1 and 4 when compared to males, which corresponded to values which were 53% and 41% lower. The values for males and females were not significantly different during Months 2, 3, and 5.

Mean fat-free weight was 75.5 ± 5.0 kg for males and 51.2 ± 7.5 kg for female swimmers. No significant relationships were observed between post-exercise CPK levels and fat-free weight in either males ($r=0.31$) or females ($r=0.14$) during any of the months. In addition, the difference between these correlations was not statistically significant.

**Discussion**

There has been considerable controversy in the literature concerning the magnitude of changes in serum CPK following exercise (3, 6, 10). This is a result of several confounding variables: subjects in varied states of training, time lapse between blood sampling and cessation of exercise, relative intensity of exercise, and duration of the exercise. An important finding of this study was that another variable, gender, must also be included in the above list. This study demonstrated that the CPK response to swim training was different in male and female swimmers of equal training status, whose training was similar in relative intensity and duration. The sex difference was most evident during the intense training period and absent during the taper period. This suggests that greater muscular stress is experienced by males during heavy training and so they may require relatively more rest for optimal performance. Male swimmers did lift heavier weights than females but the ratio of pounds of weight lifted to body weight was similar throughout training. Male swimmers also trained with higher swimming speeds than female swimmers. However, the relative intensity of swimming was similar since intervals for training were based on a certain percent of maximal speed. Also, the difference in CPK levels can not be fully explained by differences in lean body mass between males and females. Since males have greater absolute muscle mass and CPK is a muscle enzyme, this might have partially explained the higher male values. How-
ever, our results indicated a weak correlation between fat-free weight and serum CPK. Therefore, the reason for the differential response in male and female swimmers can not be fully explained by these data.

Another interesting finding was that CPK levels decreased during the season in both male and female swimmers. Peak values were attained early in the season (Month 1) as opposed to later months when both the quantity and quality of weight training and swimming had increased. However, during the taper period, in which training distance decreased but intensity remained high, the CPK levels fell to their lowest point for both males and females. These results support the findings of Burke et al. (2), that CPK levels appear to reflect training distance more than training intensity. However, in our observations, CPK levels did not increase proportional to increases in total training distance during mid-season. This suggests the swimmers in the present study adapted to the stress of training during the season to a greater extent than the swimmers in the Burke et al. study. A reduced CPK response to maximal exercise following training has been previously reported by Hunter and Critz (5) and Nuttall and Jones (11).

Another factor which could explain the difference in results between this study and Burke et al. might be the elapsed time between blood sampling and the last weight training session. Subjects in this study had approximately 45 hours to recover from swim and weight training compared to 10-12 hours in the Burke study. Elevated CPK values have been found one day following weight training (7) suggesting that heavy-resistance work might be responsible for CPK efflux into the plasma. Peak levels for CPK have been found to occur 11-15 hours after exercise, followed by a gradual decrease over the next 24 hours (6). Since the swimmers in this study had more recovery time from weight training (at least 45 hours) prior to blood sampling, this might account for the lower values. However, the effect of weight training, itself, upon CPK would be hard to predict from the design of this study.

The CPK values obtained in running studies appear to be higher than those found after swimming. Post-exercise CPK values obtained in this study ranged from 60 to 650 I. U./L. These values are considerably lower than those reported in runners following marathon distances. Lathan and Cantwell (8) reported a value of 2,676 I. U./L after a 24 hour run of 269.4 km, and Siegel et al. (14) found mean values of 3424 I. U./L in fifteen runners 24 hours following the Boston Marathon. Other investigators (3) found an 85% increase in mean CPK values following running compared to only a 20% increase after swimming. Therefore, the magnitude of CPK elevation in swimmers may not be nearly as great as that found in long-distance running.

Haralambie et al. (4) reported that CPK levels may be more affected by "impact-type" exertion (i.e. marathon running, speed skating, race walking), than other forms of exercise. However, the mechanism responsible for these higher values remains to be elucidated.

Some authors have noted a possible relationship between serum CPK levels and performance times in distance running. Siegel et al. (14) found an inverse relationship between post-exercise CPK elevation and finishing times of runners in the Boston marathon. Runners who completed the marathon under three hours and thirty minutes (3:30) had CPK levels three times as great (4433 I. U./L). Thomas and Motley (16) have also reported an inverse relationship between post-exercise serum myoglobin level and finishing time in a triathlon. The authors found that the fastest finishers elicited the highest myoglobin levels following the 3 hr. competition. Myoglobin levels in the blood have been found to be highly correlated with CPK levels (12) and so might also merit further study in highly-trained swimmers. A relationship between performance and post-exercise CPK levels has not yet been established in swimming.

Elevations of CPK early in the season suggest possible chronic muscular stress. This stress appears to be different for males and females during heavy training, but similar during taper training. Perhaps, elevations in CPK above the normal range during the taper phase may signal the coach to give an individual additional rest until serum CPK returns to normal. For example, during pre-season, as a swimmer performs a specific workload, his or her CPK may increase above 200 I. U./L. But, as the swimmer becomes more trained, that same work-out might result in CPK values < 200 I. U./L. Therefore, CPK levels late in the training season exceeding some "critical" value might indicate possible overtraining. It is important to realize that much variation exists among individuals and, therefore, meaningful comparisons can only be made across time for each individual under a standardized set of testing conditions. In addition to monitoring CPK, other measures such as resting heart rate, serum myoglobin, blood hemoglobin, concentration of blood lactate in response to a standardized work bout, glycogen stores, persistent losses in body weight or appetite, fatigability and personality changes may also provide insight into the training status of an individual swimmer. Therefore, serum CPK levels could serve as one indicator for coaches to determine overtraining in swimmers if responses were measured after a standardized work bout over the training season.

Conclusions

During most of a swim season, male swimmers appear to have greater serum CPK levels than females.
both at rest and immediately following heavy exercise. However, this difference in serum CPK becomes smaller during the taper, when the quantity of swim training and intensity of weight training is reduced. This discrepancy in serum CPK might be explained by higher absolute intensity of swimming or weight training by the males even though the relative intensity was apparently similar. The higher serum enzyme levels in males are not related to their greater fat-free weight. Whether male swimmers require relatively more rest for peak performance compared to female swimmers can not be clearly demonstrated from this study. It is also important to identify each individual's "normal" values for post-exercise and resting CPK, since there is much variation between individuals. Therefore, CPK measurements could be used along with other possible indicators of overtraining in male and female swimmers. Such parameters should be monitored for each swimmer throughout the training season in order to make meaningful comparisons throughout the swimmer's career and ensure accurate assessment of the individual's training status.

References

A Maximal Multistage Swim Test to Determine the Functional and Maximal Aerobic Power of Competitive Swimmers

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Abstract

The purpose of this experiment was to develop a useful test to predict the functional (FMAP) and maximal power (MAP) in competitive swimming. The approach used consisted in establishing the relationship between swimming velocity (Sw, m·s⁻¹) and oxygen consumption (VO₂, ml·kg⁻¹·min⁻¹) as assessed by retroextrapolating the О₂ recovery curve to time zero of recovery. To reduce the interindividual variations in the О₂ requirements (or cost) of swimming, the arm stroke index (ASI) consisting in the ratio of the number of arm strokes for 125 m to free swimming velocity, was used as a covariable. This ASI was strongly correlated with VO₂ to swim one km at 0.8 m·s⁻¹ (r = 0.936) and was also highly reliable (r = 0.935). Thereafter, VO₂ was measured at submaximal and maximal velocities during a multistage swim test (initial velocity of 1.0 m·s⁻¹; increments of 0.05 m·s⁻¹ every 2 min): VO₂ = 96.94 (Sw) + 0.123 (ASI) - 69.23, r = 0.877, SEE = ± 11%, n = 14 competitive swimmers and 53 observations. In addition of having a fairly acceptable predicting power for MAP, this test presents the advantage of measuring the maximal aerobic swimming velocity, also termed the FMAP, which is, on a practical point of view, as important as the MAP.

Key words: swimming; maximal aerobic swimming velocity; oxygen consumption; index of energy cost

Introduction

Prediction of maximal aerobic power (MAP) in running has been carried out by way of different testing procedures (4,20,21). For reasons such as simplicity, financial cost, etc., mass field tests are very popular. In recent years, alternatives to the widely used 12-min run test (2) have been proposed to correct for the dependence of this test on factors such as motivation and anaerobic capacity. These alternatives include a maximal multistage running track test (10) and a maximal multistage 20-m shuttle run test (11). These field tests although predicting MAP (VO₂ max) are subjected to random error, some individuals being more (or less) efficient than the average one. The predicted score assumes that each individual behaves as the average one, which is not exactly true. However, the predicted score per se (i.e., maximal swimming or running velocity) is as (if not more) important as the true MAP. What is the use of having a high MAP if one also has a poor efficiency. The functional maximal aerobic power (FMAP), a combined index of MAP and mechanical efficiency, is thus a better indication of aerobic performance. Field tests are interesting in that they not only provide an estimate of MAP but also determine exactly the FMAP specific to the type of activity being performed during the test.

In swimming, very few indirect field tests have been constructed to predict MAP (6). The main reason for this situation is probably the large interindividual variations in the energy cost of swimming (16,18). Such a test in swimming is, however, important due to the fact that especially in swimming, training is specific to the type of activity used both for training and testing (7,13,14). The purpose of the present investigation was: 1) to validate an arm stroke index (ASI) that could be easy to measure and that could be used to reduce the interindividual variation or random error.
found in predicting VO₂ from swimming velocity (SV), and 2) to construct a maximal multistage swim test that could be used to evaluate the functional maximal aerobic power in swimming and to predict the MAP.

Methods

Two series of experiments were conducted. In the first series of experiments the validity and reliability of an index of energy cost were tested. In the second series a maximal multistage swim test was constructed.

Index of energy cost

The index of energy cost used in this experiment, to be referred to as the arm stroke index (ASI), was based on a study presented by Craig and Pendergast (3), and consisted in the number of arm strokes for a distance of 125 m (free style) divided by the swimming velocity in m*s⁻¹. The swimmer was asked to swim 150 m, but the swimming velocities and the arm strokes for the last 125 m only were tabulated. The swimming velocity was calculated for each length and averaged for the whole 125 m. Arm strokes for each 25 m of the 125 m were tabulated by an observer and the total of these arm strokes was used in the calculation of the index:

Arm Stroke Index (ASI):

\[
\text{Number of arm strokes (125 m)} / \text{Swimming velocity (m*s⁻¹)}
\]

In a first experiment, 19 physical undergraduate students (11 females and 8 males; age: 18-23 years), registered in a swimming class, had their arm stroke index determined for different swimming velocities (0.8, 0.9, and 1.0 m*s⁻¹) and compared to a swimming velocity freely chosen by each subject. In the cases where the swimming velocity was prescribed, sound signals were emitted at specific cadences such that swimmer speed was determined by the swimmer equidistant red pylon markers (3 per 25 m length) on each sound signal. For the free velocity swim, subjects were instructed to use a swimming velocity with which they would be able to swim a long distance (such as one km). No flip turns were allowed during any of these measurements.

In order to test the reproducibility of this measure, 12 of the 19 swimmers had their arm stroke index determined twice (one week apart) using the free swimming speed. The validity of the index was determined by comparing the results of 8 of the 19 subjects to a direct measurement of energy cost in liters of oxygen required to swim one km (VO₂/d) using the front crawl (19) at the velocity of 0.8 m*s⁻¹. Oxygen uptake (VO₂) was measured every 5 min during the 20 min swim and the total cost to swim the whole km was calculated from these values. Expired air was collected during one min in a Douglas bag attached to a cart which followed the swimmer along the side of the pool. Oxygen and carbon dioxide fractions in expired air samples were determined on Beckman E-2 and LB-1 gas analysers respectively. Expired volumes were measured in a Tissot spirometer.

Maximal multistage swim test

A pilot study on a small group of experienced swimmers revealed that an increase in swimming velocity of 0.05 m*s⁻¹ was comfortable and corresponded to an increase of approximately 1 Met (3.5 ml*kg⁻¹*min⁻¹) for this particular group of swimmers. After another pilot study conducted on a group of competitive swimmers, it was decided to start the test at 1.0 m*s⁻¹ and to increase the speed by 0.05 m*s⁻¹ approximately every 2 min. The exact time for each stage was, however, set in agreement with the moment where the swimmer reached one extremity of the pool (Table 1). This was necessary for the collection of expired gas during the validity experiment. In the final version of the test, the swimming speed of each stage is increased every 2 min exactly. As for the ASI experiment, the pace was set with audio signals, audible underwater, emitted at specific frequencies using a prerecorded tape. An observer walking along the side of the pool at the same specific cadences was also used as a reference point for the swimmers. All swimming experiments were performed in a 25-meter pool in which the water temperature was maintained at 27°C.

Fourteen currently active competitive swimmers (9 females and 5 males) with a mean age (+ SD) of 18 ± 2.5 (14-22) years had their oxygen uptake determined after several stages of the swim test. For each measurement of oxygen uptake at a predetermined stage, the swimmer had to swim all the preceding

<table>
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</tr>
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stages. For most of the cases only one measurement of oxygen uptake per swimmer was made in the same day. For such cases where two determinations of oxygen uptake were made in a single day (stages with the lowest swimming velocities) a resting period of approximately 45 to 60 min was allowed between the swim bouts. All of these swimmers had also their arm stroke index determined as previously described. During the multistage swim test the swimmers were free to use flip turns if they wanted to. Oxygen uptake was assessed by establishing the \( \dot{V}O_2 \) recovery curve following the end of the exercise. The Douglas bag method was used for the collection of four consecutive 20-s samples of expired air immediately at the end of the swim. A single exponential regression curve was fitted to four points with the least-squares regression technique, and \( \dot{V}O_2 \) at time zero of recovery was obtained by retroextrapolating the \( \dot{V}O_2 \) recovery curve. The retroextrapolation method has previously been found valid \((r = 0.92)\) and accurate for the determination of maximal (9) and submaximal (12) \( \dot{V}O_2 \) values. Submaximal values under 45 ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\) were corrected for possible underestimation according to the equation presented by Léger et al. (12). The retroextrapolation method has also successfully been used in swimming (17). Oxygen, \( \dot{CO}_2 \), and expired volumes were analyzed as previously described for the direct measurement of energy cost. Attention was paid to starting and ending the 20-s collection period at the same phase of the respiratory cycle and to timing this period exactly.

To establish the reproducibility of the test, 19 competitive swimmers (9 males and 10 females) twice performed the maximal multistage swim test one week apart in groups of 5-6 subjects at a time.

The difference between mean values were tested using the Student \( t \) test and were considered significant if \( p \) were less than 0.05.

Results

The relationships of the arm stroke index (ASI) and the swimming velocity (\( S\bar{V} \)) are shown in Fig. 1. The common feature of these curves is that the ASI improves (i.e. a decrease) as the \( S\bar{V} \) increases up to 1.0 m\( \cdot \)s\(^{-1}\). Compared to the last \( S\bar{V} \) measured, the ASI measured at a free \( S\bar{V} \) did not show any statistical differences (paired \( t \)-test). These free \( S\bar{V} \) corresponded respectively to (X ± SD) 1.01 ± 0.09, 1.03 ± 0.1, and 0.97 ± 0.06 m\( \cdot \)s\(^{-1}\) for the whole group of swimmers, the females, and males taken separately. The values of the ASI obtained at the free \( S\bar{V} \) were highly correlated \((r = 0.938 \text{ and SEE } = 9.0\%)\) to those obtained for the same subjects using the direct energy cost measurements (Fig. 2). Test and retest one week apart (Fig. 3) indicated that the ASI at free \( S\bar{V} \) was highly reproducible \((r = 0.935 \text{ and SEE } = 6.4\%)\). The means (± SD) of the two tests were 111.3 ± 18.9 and 111.9 ± 18.4 \((p > 0.05)\).

Validity of the maximal multistage swim test for the assessment of \( \dot{V}O_2_{max} \)

The second series of experiments on 33 \( \dot{V}O_2 \) measurements yielded the following regression equation for \( \dot{V}O_2 \) (\( y \), ml\( \cdot \)kg\(^{-1}\)\( \cdot \)min\(^{-1}\)) on the swimming velocity (\( S\bar{V} \), m\( \cdot \)s\(^{-1}\)) and the arm stroke index (ASI), number of arm strokes (125 m)/free \( S\bar{V} \) during the multistage swim test:

\[
y = 96.94 \, (S\bar{V}) + 0.123 \, (ASI) - 69.23
\]

with a correlation coefficient of 0.877 and a standard
Fig. 2 Relationships of the Arm Stroke Index (number of arm strokes, 125 m/Sv) and the energy cost of oxygen required to swim a distance of one km at a velocity of 0.8 m/s (VO₂/d).

Error of estimate of 11.0% (Fig. 4). Test and retest one week apart (Fig. 5) indicated that the maximal multistage swim test was highly reproducible (r = 0.991 and SEE = 8.2%). The means for the two trials were 6.57 ± 4.1 and 6.48 ± 4.0 stages completed (P > 0.05).

Fig. 3 Reproducibility of the Arm Stroke Index (number of arm strokes, 125 m/Sv) using free swimming velocities.

Discussion

One of the main problems in establishing a maximal multistage swim test to predict aerobic power is to control for the large interindividual variability in energy cost. Two solutions have been put forth in the present study to overcome this difficulty. The first step was to construct the test using only competitive swimmers. This approach presents the advantage of increasing the homogeneity of the group of subjects by largely reducing the variability in energy cost. Even though differences in energy cost can still be found among elite swimmers (16), it is largely less than if recreational swimmers had been included in the group.
of subjects studied. On the other hand, using only competitive swimmers limits the present application of the test to this particular class of swimmers. The second main by which variations in energy cost have been taken into account was to determine an index to estimate it and to make corrections for it. This index, to be useful, had to be easy to get, should not require sophisticated apparatus (5), and had to give a good estimate of the overall technical ability of the swimmer. Based on the work of Craig and Pendergast (3), the number of arm strokes divided by the swimming velocity, which is the equivalent of the stroke-velocity curve (3), is probably the best index of the overall technical ability of a swimmer. Evaluation of swimming ability on the other hand, involves consideration of drag and efficiency (18). The validity of the present index is shown by the high correlation with the directly measured swimming energy cost (VO₂/d). This VO₂ has been shown in turn to provide a valid quantitative measure of the technical ability of a swimmer (19).

During the maximal multistage swim test, the ASI can be calculated for each different stage. However, as shown in Fig. 1, this index changes with the swimming velocity and probably reaches an optimal combination of number of stroke and distance per stroke (3). It is also interesting on a practical point of view to observe that the index at a swimming velocity freely chosen by the subjects can lead to a value probably very close to the optimal value for this index. Even though the ASI values have not been obtained for velocities higher than 1.0 m·s⁻¹ in the present experiment, this swimming velocity being close to the maximal velocity for this class of swimmers, it can be postulated that higher swimming speeds could have led to a reincrease in the ASI values (3). Based on the above considerations, it can be concluded that the present arm stroke index provides a discriminative and reproducible measure of swimming proficiency, and that this measurement can easily be obtained during the maximal multistage swimming or by swimming a certain distance (150-200 m) at a freely chosen swimming velocity.

Validity of the maximal swim test

Based on the 53 observations collected among 14 competitive swimmers, it was found that swimming velocity, after correction with the arm stroke index, could predict the swimming VO₂ with an r of 0.877 with a standard error of estimate of 11% of the mean. Although these results are highly comparable with other indirect tests (11) the individual error (11%) remains quite large and should be taken into account in interpreting the results of the test. It is also noteworthy to mention that the little number of observations made above 1.35 m·s⁻¹ might affect the predicting power for VO₂ at these velocities.

The present relation between swimming velocity and VO₂ was obtained by directly measuring VO₂ at the end of the exercise period using the backward extrapolation method. Although this method can be considered as an indirect measurement of VO₂ in field conditions, it has been shown to be valid (r = 0.92) and accurate (SEE = 3.21 ml·kg⁻¹·min⁻¹) for the determination of VO₂max after a maximal multistage test (10). The retroextrapolation method has also been shown to be valid to predict submaximal VO₂values, with however, a small underestimation (<6%) for values between 30 and 45 ml·kg⁻¹·min⁻¹, that can be corrected with the proper equation (12). More than 70% of the VO₂ measured during the multistage swim test were above 45 ml·kg⁻¹·min⁻¹. No comparisons with conventional tests, such as treadmill or cycling direct or indirect tests, have been attempted to further validate the multistage swim test. The reason for this is the specificity of the test. Many studies (7,13,14,15) have convincingly demonstrated the highly specific nature of swimming for training and testing. Even the type of tests used directly in swimming can lead to conflicting interpretation (8). Although flume swimming, free swimming, and tethered swimming can yield similar VO₂max results (1), higher VO₂max values have been found during unimpeded swimming using the backward extrapolation method than during running (17). For this reason, it becomes difficult to interpret a possible lack of correlation between unimpeded swimming and, let say, free swimming VO₂ values, as being the result of a weakness in the validity of the multistage swim test or the result of a weakness in the specificity of the free swimming test.

The construction of a maximal swimming test using unimpeded swimming was imperative for two reasons: 1) it allows to respect the real nature of the activity such as breathing pattern, body rotation, and flip turns; 2) it also allows a true relationship between the swimming velocity and the maximal aerobic power. The knowledge of this relationship on a practical point of view is probably more important than the prediction of VO₂max. Accordingly, the present multistage swim test gives the swimming velocity at which the maximal aerobic power is reached. This swimming velocity could be termed the maximal aerobic swimming velocity or the functional maximal aerobic power. This maximal aerobic swimming velocity can be used to determine training velocities as well as to evaluate the aerobic effects of a training programme. The maximal aerobic swimming velocity, however, includes the mechanical component of the stroke, and could be changed by variations in technical ability. This will not, however, make much differences on a practical point of view.
since what is really important for the coach and the swimmer is the maximal aerobic swimming performance and that includes the mechanical and energetic components.

In summary, the maximal multistage swim test as described, with stages increasing by 0.05 m·s⁻¹ every 2 min, is highly reliable to measure the functional maximal aerobic power in swimming. When the results of the test are combined with an index of energy cost, described as the number of arm strokes (125 m) divided by the freely chosen swimming velocity, they appear to provide a valid and reliable tool to predict the maximal aerobic power of competitive swimmers.

Acknowledgements

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References

Pulmonary Function Measurements In U.S. Elite Swimmers

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Sports Physiology Laboratory
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Introduction

The increased metabolic demand of competitive swimming requires an effective system to transport oxygen from the atmosphere to the working muscles. The respiratory system is the interface between the environment and other organ systems which provides for gas exchange. Several laboratory measurements can describe the effectiveness of respiratory function including spirometry, and pulmonary diffusing capacity. Spirometry provides an index of ventilatory capacity and diffusing capacity influences the availability of oxygen to transport across the alveolocapillary membrane. The measurements of pulmonary function in elite swimmers may identify effects of chronic physical training or characteristics related to genetic endowment.

Larger than average lung volumes have been reported for marathon runners (5), speed skaters (7), elite middle distance runners (9), and age-group swimmers (6). Vital capacity has been the predominant measurement which was larger in athletes than non-athletes. Another study, however has demonstrated no consistent difference in examining lung volumes in the athletic versus the nonathlete (10).

While elite swimmers appear to be a special group of athletes having larger vital capacities than nonathletes and an exercise breathing pattern which is unique to the sport, they have not been fully evaluated in terms of pulmonary function. The purpose of this study was to evaluate the flow, volume, and diffusion characteristics and to compare them with other athletic groups and their normal predicted values based on gender, height, and age.

Methodology

The subjects in this study were twenty female and eighteen male elite swimmers competing in the 1984 U.S. National Short-Course Championships in Indianapolis or the Olympic training camp in Mission Viejo in July, prior to the Olympic Games. This testing was part of the U.S. Swimming Sports Medicine Committee's Elite Athlete testing program. Testing was done prior to competition or workout.

Basic anthropometric data were obtained and are presented in Table I. This information was used for file management and computation of regression equations for individual predicted values.

The following spirometric measurements were made with an on-line mass flow meter system (Gould Sentry 82): forced vital capacity (FVC), forced expiratory volume in one second (FEV1), peak expiratory flow (PEF). Static lung volumes were determined by nitrogen washout technique with the same system for the measurement of residual volume and calculation of total lung capacity (TLC). Although numerous other values are calculated, statistical analyses were not necessary to determine differences. Calibrations were performed with a 3-liter syringe for flow and volume,

Table 1. Descriptive data on elite swimmers

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<td>Mean</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>20.3</td>
<td>17-25</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>183.1</td>
<td>175-198</td>
</tr>
</tbody>
</table>

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and the nitrogen analyzer was zeroed and calibrated with 100% oxygen and room air prior to all testing. The pulmonary diffusing capacity (DLco) was determined at rest with the single-breath technique using the Gould Sentry 88. This was a modification of the breath-holding method described by Ogilvie (8) using a gas mixture of 0.3% carbon monoxide, 9.7 helium, and 90% oxygen. The Ecolyzer Co analyzer was zeroed and calibrated prior to all testing. The gas analysis, inspired volume, and breath-holding time were used to calculate DLco in ml/min/torr. A correction factor for hemoglobin was designed into the computer program.

Duplicate measurements were made on all subjects to establish reproducibility. All measurements were made with the subject seated, and were conducted at normal room air conditions. The FVC, RV, TLC, REV,, PEF and DLco were expressed as measured values and as percent of predicted normal values.

Differences between predicted and actual measurements were determined by paired t-test with an alpha level of 0.05 chosen as the level of significance.

Results

The basic descriptive data for the subjects used to calculate predicted regressions including gender, height, and age are presented in Table 1. The mean age of the males was slightly older (2 years), and the mean height was about four inches taller than the females.

Comparisons of the means of predicted and actual pulmonary function data are presented in Table 2. Significant difference between the predicted mean and observed mean was found for FVC, FEV1, PEF, TLC, RV and DLco for both males and females. There was a definite trend in all swimmers for lung capacities, flow rates, and diffusing capacity to be greater than predicted.

Figure 1 demonstrates graphically the individual data points in a bivariate distribution of predicted versus measured vital capacity for female swimmers. Almost all data points in this group are shifted to the right of the line of identity.

Figure 2 demonstrates a fairly diverse distribution of data points in male swimmers for residual volume. Clearly, there is no trend among these athletes, but

| Table 2. Comparison of means of predicted and observed respiratory data for elite swimmers |
|-----------------------------------|----------------|----------------|------|------|------|
|                                   | Predicted Mean | Observed Mean  | Diff | %Pred | t-Scores |
| Males N = 18                     |                |                |      |       |      |
| FVC (liters)                     | 5.52           | 6.92           | +1.4 | 127   | 9.39* |
| FEV1 (liters)                    | 4.57           | 5.47           | +0.9 | 120   | 7.63* |
| PEF (1/sec)                      | 9.78           | 10.69          | +0.9 | 110   | 3.35* |
| TLC (liters)                     | 7.25           | 8.43           | +1.2 | 119   | 6.34* |
| RV (liters)                      | 1.68           | 1.46           | -0.2 | 91    | 3.89* |
| DLco (ml/min)                    | 30.60          | 42.33          | +11.9| 139   | 8.32* |
| Females N = 20                   |                |                |      |       |      |
| FVC (liters)                     | 4.11           | 5.04           | +0.9 | 123   | 10.38*|
| FEV1 (liters)                    | 3.67           | 4.27           | +0.6 | 116   | 7.31* |
| PEF (1/sec)                      | 7.11           | 8.01           | +0.9 | 113   | 3.52* |
| TLC (liters)                     | 5.46           | 6.28           | +0.8 | 115   | 8.13* |
| RV (liters)                      | 1.39           | 1.20           | -0.2 | 96    | 3.15* |
| DLco (ml/min)                    | 24.40          | 30.98          | +6.6 | 127   | 6.60* |
this finding has interesting consequences which will be discussed later.

Comparing pulmonary function results from this study with previously published results for the same age and height male athletes and non-athletes demonstrates greater mean values for FVC, FEV₁, TLC, and DLco (Table 3). Elite swimmers were definitely more different from their untrained counterparts. This is shown graphically in Figures 3 and 4 with the arrow pointing to the swimmers' results compared to other athletic groups from the Olympic Training Center (unpublished data). Again, quite clearly swimmers were more different (distances from the line of identity) than other athletes.

**Discussion**

Results from this study revealed larger lung compartments and flow rates for elite swimmers than their normal predicted values and similar (age, height, and sex) athletic groups. However, residual volume was found to be slightly less than predicted with a large degree of variability. This finding is interesting and is being investigated further because of its potential measurement error in determining body density by underwater weighing. Many laboratories use predicted volumes for residual volume estimation for both athletes and non-athletes. The results from this study demonstrate the potential for large error in measurement using the latter technique.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Activity</th>
<th>n</th>
<th>VC</th>
<th>FEV₁</th>
<th>RV</th>
<th>TLC</th>
<th>DLco</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Swimmers</td>
<td>18</td>
<td>6.92</td>
<td>5.47</td>
<td>1.46</td>
<td>8.43</td>
<td>42.5</td>
</tr>
<tr>
<td>Magel (6)</td>
<td>Swimmers</td>
<td>10</td>
<td>6.37</td>
<td>5.34</td>
<td>1.78</td>
<td>8.15</td>
<td>39.0</td>
</tr>
<tr>
<td>Maksud (7)</td>
<td>Skaters</td>
<td>9</td>
<td>5.83</td>
<td>4.97</td>
<td>1.67</td>
<td>7.54</td>
<td>35.2</td>
</tr>
<tr>
<td>Holmgren (4)</td>
<td>Trained</td>
<td>10</td>
<td>5.85</td>
<td>4.83</td>
<td>1.53</td>
<td>7.55</td>
<td>31.1</td>
</tr>
<tr>
<td>Raven (9)</td>
<td>Runners</td>
<td>9</td>
<td>5.78</td>
<td>4.55</td>
<td>1.50</td>
<td>7.22</td>
<td>27.3</td>
</tr>
<tr>
<td>Astrand (3)</td>
<td>Untrained</td>
<td>45</td>
<td>5.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although the effects of physical training on pulmonary function during growth are not fully understood, it has been proposed that the high vital capacity is probably due to increased development of the respiratory muscles. This hypothesis is supported by the finding that peak expiratory flow (PEF, Table 2), is greater than predicted in swimmers and RV is less. This indicates that training the respiratory musculature allows one to "squeeze" harder and also get a little more air out. Without question, the explosive breathing pattern required for competitive swimming would provide the mechanism for this adaptation.

The total lung capacity was greater than predicted in swimmers and also greater than other athletic groups reported. This finding was consistent for both males and females even though the RV was less. Keeping in mind that TLC is the sum of the vital capacity and the RV, it is somewhat surprising. As both the VC and the TLC are well above normal in this study, it indicates an adaptation among swimmers not found in other athletic groups. This may be done, in part, to the shift in functional residual capacity during swimming to maintain improved buoyancy. Simply, more air in the thorax (hyperinflation), the better one floats.

The mean values for DLco for both males and females were significantly higher than predicted and also higher than other reported athletic groups. Although other studies do not agree on significant dif-

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**Figure 3.** Predicted vs. measured vital capacity for various endurance sports. The arrow indicates this population of female swimmers.

**Figure 4.** Predicted vs. measured FEV₁ for various endurance sports. The arrow indicates this population of female swimmers.
ferences between measured and predicted in well-trained athletes, the current study would support the finding. The improved ability to transfer oxygen is presumably facilitated by an increase in hemoglobin and blood volume in the pulmonary capillaries. The hemoglobin values determined previously were not significantly higher than normal and leads one to believe that pulmonary capillary volume is increased. Another possible explanation for the increase could be due to alteration in the alveolo-capillary membrane. The underlying mechanism for such an adaptation is not understood.

The data reported in this study follow three general trends: (1) The lung capacities and flow rates were larger in elite swimmers than predicted based on normative data and larger than other athletic groups reported; (2) residual volumes were smaller and quite variable; and (3) pulmonary diffusing capacities were much larger than predicted and slightly larger than other athletic groups.

The significantly elevated values of pulmonary function measured in these athletes suggests their arduous training does indeed bring about adaptive changes, unless they were genetically endowed with such traits, which in turn helped in their choice of swimming as a sport to excel. Unfortunately, no data is available for these athletes prior to beginning serious training. It is suggested from these results that a longitudinal study of pulmonary function be conducted on age-group swimmers to follow them from ages 8-18 in order to answer this question.

References


The Effect of Sprint-Assisted and Sprint-Resisted Swimming on Stroke Mechanics

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Abstract

Four male and two female competitive swimmers, ages 13 to 17, were filmed sprinting butterfly. They swam approximately 40 feet under three conditions: un tethered, partially-tethered by a swim belt, and using the swim belt as a means of sprint-assisted training. The films were digitized and the resulting coordinates analyzed by computer. The subjects required less time to complete their underwater armstrokes during the sprint-assisted trials and more time to complete them during the sprint-resisted trials. They tended to take shorter armstrokes during the sprint-assisted trials. Stroke lengths were shorter for some and longer for others during the sprint-resisted trials. They tended to use slower hand speeds during the sprint-resisted trials. Linear hand velocities were slower for some and faster for others during the sprint-assisted trials. The subjects’ hands followed different paths during the three trials. They exhibited differing degrees of maximal elbow flexion at mid-stroke, but there was no consistent direction to these differences. Most of the swimmers flexed their wrists more at mid-stroke during both sprint-assisted and sprint-resisted trials, and hyperextended their wrists more during sprint-assisted trials. They tended to hyperextend their wrists less during sprint-resisted trials.

Key Words: Aquatics, Biomechanical Analysis, Biomechanics, Competitive Swimming, Hydrodynamic Analysis, Kinematics, Sprint-assisted, Sprint-resisted, Swim Belt, Swimming, Tethered Swimming

Introduction

Since muscular power is a valuable component of sprint speed, many training methods have been developed to improve strength by artificially increasing the resistance a swimmer works against. This form of training has been termed sprint-resisted and is characterized by swimming against surgical tubing or other resistance producing devices. Although sprint-resisted methods of training continue to be used in many training programs, the small amount of research that is available concerning it’s effect on swimming speed has not been favorable. Speed did not improve in most cases (4, 5, 8, 9).

A possible reason for this may be that sprint-resisted training has a detrimental effect on stroke mechanics. A recent study involving national level competitive swimmers showed such an effect (6). The swimmers sprinted approximately 40 feet while untethered and while partially tethered. During the partially tethered portion of the study, the subjects were harnessed to the control mechanism of a biokinetic swim bench that had been adapted for in-water use. The following significant differences were noted between the subjects’ untethered and partially-tethered trials: When partially-tethered the subjects required more time to complete their underwater armstrokes, the average angular velocity of their hands was slower, their average backward hand velocities and their average upward hand...
velocities were slower, they spent more time in the final portion of their strokes, and they made their catch a deeper point. In short, the swimmers’ stroke mechanics changed in a way that resulted in a shorter, slower underwater armstroke.

There is cinematographical evidence that sprint-resisted training has produced a similar effect on runners (3). Runners were found to shorten their strides, change their body lean and change their foot placement in ways that reduced their efficiency.

Because of the possibility that sprint-resisted training had a detrimental effect on running mechanics, track coaches have developed an alternative method, sprint-assisted training, to improve sprint speed. They had athletes run downhill at speeds exceeding those they could achieve on a level surface. They have also used treadmill running where the speed of the belt was increased to simulate 100 yd. dash speeds that were faster than 9.0 seconds.

A cinematographic study (3) indicated that certain sprint-assisted methods resulted in an increase in stride length with no decrease in stride rate. This is a desirable change that is believed to improve running speed. It would be similar to a swimmer applying force over a greater distance with no decrease in turnover rate. Runners have increased their unassisted 100 yd. dash times from 10.5 to 9.9 seconds after using sprint-assisted methods for only five weeks (11).

Since sprint-assisted training had been shown to increase the speed of runners, Rowe, Maglischo, and Lytle (10), studied the effects of this form of training on swimming speed. Swim fins were used as the assistive device. Following completion of the training period, the average 25 yd. freestyle speed of the experimental group improved significantly more than that of the control group. The average improvement of the members of the control group was 0.41 seconds greater than that of the experimental group.

Other methods of sprint-assisted training have become popular over the past several years. One method that has shown particular promise involves the use of a swim belt that is constructed of thin-walled surgical tubing. The tubing is tied to the end of the pool below the water level and the swimmer walks down the pool stretching the tubing as he goes. After reaching the other end, the swimmer sprints back as fast as possible while allowing the “snap-back” of the surgical tubing to assist him in swimming faster than he can swim unassisted.

Purpose

The purpose of this study was to determine the effect of sprint-assisted and sprint-resisted training on stroke mechanics. The procedure used was to film swimmers while sprinting untethered, while partially-tethered by a swim belt, and while using the swim belt as a means of sprint-assisted training.

Methods and Procedures

Subjects:

The subjects were six competitive swimmers, four males and two females. They were between the ages of 13 and 17. A profile of the subjects is presented in Table 1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age</th>
<th>Time for 100 yards Butterfly</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.K.</td>
<td>Male</td>
<td>16</td>
<td>53.50</td>
</tr>
<tr>
<td>R.S.</td>
<td>Male</td>
<td>14</td>
<td>57.55</td>
</tr>
<tr>
<td>P.W.</td>
<td>Male</td>
<td>13</td>
<td>1:00.45</td>
</tr>
<tr>
<td>S.P.</td>
<td>Female</td>
<td>15</td>
<td>1:09.75</td>
</tr>
<tr>
<td>M.L.</td>
<td>Male</td>
<td>17</td>
<td>55.35</td>
</tr>
<tr>
<td>M.B.</td>
<td>Female</td>
<td>13</td>
<td>59.82</td>
</tr>
</tbody>
</table>

Testing Equipment:

The subjects were filmed with two 16mm movie cameras that were secured in plastic underwater housings. Each subject was filmed from the side and front simultaneously. The cameras were operating at 48 f.p.s.

An orthogonal reference measure was placed in the field of view. It consisted of two poles, each three feet long, that were mounted on a support base that was placed on the bottom of the pool directly beneath the path of the swimmer.

A strobe light was also placed in the field of view. It was operated by an assistant who activated it when the swimmers’ hands entered the water after coming into the field of view. The flash was used to synchronize frames from the two cameras for later analysis.

Twenty feet of thin-walled surgical tubing was used for both the sprint-assisted and sprint-resisted testing. It was attached to a belt made of webbing that was placed around the swimmers’ waists.

Each subject was filmed while swimming 25 yard butterfly sprints under each of three conditions: untethered, sprint-assisted, and sprint-resisted. The untethered sprint began with a push off the wall and was swum as fast as possible. For the sprint-assisted trial the tubing was attached to the wall in front of the swimmers and pulled them forward as they sprinted one length of the pool. In the sprint-resisted trial the tubing was attached to the wall behind the swimmers and resisted their forward motion as they sprinted down the pool.

The subjects swam their untethered trials first. They were then given one or two practice trials using the
sprint-assisted and sprint-resisted procedures for the purpose of becoming familiar with the apparatus. This small number of trials was sufficient because all of the subjects used both the sprint-assisted and sprint-resisted procedures on a regular basis in training. The sprint-assisted and sprint-resisted trials were filmed immediately following the practice trials. The figures in Table 2 show each subject’s average forward velocity during each of the three trials; untethered, sprint-assisted and sprint-resisted.

Table 2. Average Forward Velocity Per Stroke

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Average forward velocity in ft./sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untethered</td>
</tr>
<tr>
<td>M.K.</td>
<td>5.59</td>
</tr>
<tr>
<td>R.S.</td>
<td>5.60</td>
</tr>
<tr>
<td>P.W.</td>
<td>5.70</td>
</tr>
<tr>
<td>S.P.</td>
<td>5.40</td>
</tr>
<tr>
<td>M.L.</td>
<td>4.33</td>
</tr>
<tr>
<td>M.B.</td>
<td>4.64</td>
</tr>
</tbody>
</table>

3.5 ft./sec = 21.43 secs. for 25 yds.
5.5 ft./sec = 13.64 secs. for 25 yds.
6.5 ft./sec = 11.54 secs. for 25 yds.

Data Reduction:

The films were analyzed with an Eiki Motion Analyzer and a Numonics Digitizer, Model 1224. For each subject, one complete underwater armstroke of the right arm was digitized during the untethered, sprint-assisted and sprint-resisted trials. Digitizing commenced when the right hand was seen entering the water and continued until the swimmer’s hand had left the water. Every second frame was digitized. The position of seven segmental endpoints and a reference point were determined in each digitized frame. The endpoints were:

1. The tip of the middle finger.
2. The base of the first finger.
3. The base of the little finger.
4. The center of the wrist.
5. The center of the elbow.
6. The acromion process of the shoulder.
7. The center of the hip.

Linear and angular parameters were computed by two computer programs, a three-dimensional analysis program and a two-dimensional analysis program, that were specifically designed to analyze swimming strokes.

Data Analysis:

The underwater armstroke was partitioned into the following segments for purposes of analysis:

1. The Entry. This portion began with the entry of the hands and ended with the first propulsive phase of the armstroke began at the catch. The swimmers’ hands usually traveled outward, downward and forward during this phase.
2. The Downsweep. This was the first propulsive phase of the stroke. It began with the catch and continued until the hands started moving inward. The swimmers’ hands usually traveled downward, outward and backward during this phase.
3. The Insweep. This phase began with the first inward motion of the swimmers’ hands and ended when their hands had finished their inward motion. The swimmers’ hands usually traveled inward, upward and backward during this phase.
4. The Upsweep. This phase of the stroke began when their hands started to move outward from underneath their bodies and it ended when they released pressure on the water near their thighs. The usual directions of movement were outward, backward and upward during this phase.
5. The Release. This phase of the armstroke began when the swimmers’ released pressure on the water with their hands and ended when their hands left the water.

The analyses yielded the following information which was then used to compare the swimmers’ stroke mechanics on each of the three trials.

1. Stroke patterns. These were drawn by computer and compared. The stroke patterns were corrected for the forward motion of the swimmer’s bodies to compensate for the fact that they were held back in sprint-resisted trials and pulled forward during the sprint-assisted trials.
2. Total time for one underwater armstroke.
3. Average three-dimensional linear velocity of the swimmers’ right hands during one underwater stroke.
4. Three-dimensional linear displacement of the swimmers’ right hands during one underwater armstroke.
5. The displacement and velocity of the hand in each of the directions it traveled during the underwater stroke; forward, backward, downward, upward, inward and outward.
6. The greatest amount of elbow flexion, usually occurring at the end of the insweep.
7. The amount of wrist flexion during the insweep portion of the underwater armstroke.
8. The amount of wrist hyperextension during the upsweep portion of the underwater armstroke.

Results and Discussion:

The purpose of this study was to determine the effect of sprint-assisted and sprint-resisted swimming on the mechanics of the subjects’ butterfly strokes. The results indicated that their mechanics changed in a number of ways during the sprint-assisted and sprint-resisted
trials. The significance of these changes are discussed in the following sections:

**Stroke Length and Stroke Rate: (Tables 3, 4 and 5)**

Five of the six subjects completed their underwater armstrokes in less time during their sprint-assisted trials (see Table 3). These increases in stroke rate resulted primarily from reductions in stroke length (see Table 4).

All six of the subjects required more time to complete their underwater armstrokes during their sprint-resisted trials, (see Table 3). The data on three-dimensional linear hand velocities, (Table 5), shows that the decreases in stroking rate resulted primarily from reductions in hand speed. This finding is consistent with the results of a similar study where sprint-resisted swimming was compared with untethered swimming (6).

**Table 3. Time for One Underwater Armstroke**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time in hundredths of seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untethered</td>
</tr>
<tr>
<td>M.K.</td>
<td>.76</td>
</tr>
<tr>
<td>R.S.</td>
<td>.76</td>
</tr>
<tr>
<td>P.W.</td>
<td>.68</td>
</tr>
<tr>
<td>S.P.</td>
<td>.68</td>
</tr>
<tr>
<td>M.L.</td>
<td>.72</td>
</tr>
<tr>
<td>M.B.</td>
<td>.80</td>
</tr>
</tbody>
</table>

**Table 4. Stroke Length**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Stroke length in feet</th>
<th>Assisted</th>
<th>Resisted</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.K.</td>
<td>7.19</td>
<td>5.19</td>
<td>6.03</td>
</tr>
<tr>
<td>R.S.</td>
<td>6.37</td>
<td>4.43</td>
<td>Not available</td>
</tr>
<tr>
<td>P.W.</td>
<td>5.98</td>
<td>4.87</td>
<td>5.29</td>
</tr>
<tr>
<td>S.P.</td>
<td>5.11</td>
<td>5.78</td>
<td>5.63</td>
</tr>
<tr>
<td>M.L.</td>
<td>4.95</td>
<td>5.20</td>
<td>6.93</td>
</tr>
<tr>
<td>M.B.</td>
<td>5.71</td>
<td>5.63</td>
<td>5.68</td>
</tr>
</tbody>
</table>

**Table 5. Average 3-Dimensional Hand Velocities During One Underwater Armstroke**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Average hand velocity in feet/second</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untethered</td>
</tr>
<tr>
<td>M.K.</td>
<td>9.46</td>
</tr>
<tr>
<td>R.S.</td>
<td>8.38</td>
</tr>
<tr>
<td>P.W.</td>
<td>8.79</td>
</tr>
<tr>
<td>S.P.</td>
<td>7.52</td>
</tr>
<tr>
<td>M.L.</td>
<td>6.88</td>
</tr>
<tr>
<td>M.B.</td>
<td>7.14</td>
</tr>
</tbody>
</table>

Sisted trials could, on the surface, be considered a desirable training effect. This conclusion would be erroneous, however, since for most of the subjects, the increases in rate were due to a shortening of the propulsive phases of their armstrokes rather than an increase in hand velocities.

If, during the sprint-assisted trials, the subjects had increased their stroke rates without decreasing stroke lengths, this type of training might be beneficial. It should be mentioned that two of the subjects did exhibit increases in both stroke rate and stroke length during their sprint-assisted trials.

Another interesting finding was that the subjects tended to increase the backward velocity of their hands while decreasing hand speed in other directions (see Table 6). This is particularly disturbing since it indicates that sprint-assisted training may cause a shift from lift-dominated toward drag-dominated propulsion. The stroke patterns in Figures 1 and 2 also indicate that the swimmers pushed their hands backward more during the sprint-assisted trials.

The finding that all six of the subjects stroked at slower rates during their sprint-resisted trials casts serious doubt on the value of this training technique. These results together with the results of a previous study (6), indicate that sprint-resisted swimming encourages athletes to decrease both their stroke rates and stroke lengths. The stroke patterns in Figures 1 and 2 also indicate an increase in backward hand movements during the sprint-resisted trials.

**Changes In Stroke Patterns:**

The stroke patterns in Figures 1 and 2 show that four of the six subjects used a more shallow stroke during their sprint-resisted trials. They tended to stroke downward less and backward more during the first half of the underwater armstroke. They also tended to release the water sooner when swimming against resistance. This is indicated by the forward direction of the stroke patterns near the end of the underwater armstroke and was verified by qualitative analysis of the subjects' films.
The subjects' stroke patterns also changed during the sprint-assisted trials. The major difference was an increase in backward hand movements.

<table>
<thead>
<tr>
<th>Stroke Patterns</th>
<th>Side Views</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>Untethered</td>
</tr>
<tr>
<td>M K</td>
<td><img src="image" alt="Stroke Pattern" /></td>
</tr>
<tr>
<td>R S</td>
<td><img src="image" alt="Stroke Pattern" /></td>
</tr>
<tr>
<td>P W</td>
<td><img src="image" alt="Stroke Pattern" /></td>
</tr>
<tr>
<td>S P</td>
<td><img src="image" alt="Stroke Pattern" /></td>
</tr>
<tr>
<td>M L</td>
<td><img src="image" alt="Stroke Pattern" /></td>
</tr>
<tr>
<td>M B</td>
<td><img src="image" alt="Stroke Pattern" /></td>
</tr>
</tbody>
</table>

Figure 1. Stroke patterns drawn from a side view during the subjects’ untethered, assisted, and resisted trials. These stroke patterns have been corrected for the forward motion of the subjects’ shoulders.

As mentioned in the previous section, it is generally believed that greater backward hand motion indicates swimmers are using drag-dominated rather than lift-dominated propulsion. Therefore, it appears that both sprint-assisted and sprint resisted training cause swimmers to use not only different, but also less effective stroke patterns.

The tendency to release the water early during the sprint-resisted trials is, perhaps, the most serious stroke change. The final outward and upward sweep is generally considered to be the most propulsive phase of the arm stroke.

It should be mentioned that, in the authors’ opinions, some of the subjects’ stroke mechanics appeared to improve during the sprint-assisted trials. This was particularly true for those parts of the stroke where mechanics were faulty. For example, the tendency for two of the subjects to slide their hands outward and upward after entry was reduced during their sprint-assisted trials. The time spent in this movement increased when they swam against resistance.

There was also a tendency for four of the subjects, P.W., S.P., M.L., and M.B., to spend more time in the final upsweep portion during their sprint-assisted trials. This could be considered a desirable change since the upsweep is considered to be a very propulsive portion of the underwater arm stroke. On the other hand, during their sprint-resisted trials, the subjects tended to push up against the water more and to release the water sooner during the upsweep.

Differences in Maximum Elbow Flexion: (Table 7)

The maximum amount of elbow flexion used by swimmers has always had a prominent position in the literature on stroke mechanics (2). It is generally considered good technique for butterfly swimmers to flex their elbows approximately 90 degrees at mid-stroke. That is, to such an extent that their hands almost come together under their bodies during the insweep.

The subjects in this study exhibited differing degrees of maximum elbow flexion at mid-stroke. There was no consistent direction to these differences, however. That is, when compared to their untethered trials, some subjects had their elbows flexed to a greater extent and some to a lesser extent during the sprint-

![Table 7. Elbow Flexion During the Insweep](image)

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Elbow angles in degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Untethered</td>
</tr>
<tr>
<td>M.K.</td>
<td>93</td>
</tr>
<tr>
<td>R.S.</td>
<td>92</td>
</tr>
<tr>
<td>P.W.</td>
<td>103</td>
</tr>
<tr>
<td>S.P.</td>
<td>118</td>
</tr>
<tr>
<td>M.L.</td>
<td>113</td>
</tr>
<tr>
<td>M.B.</td>
<td>60</td>
</tr>
</tbody>
</table>
assisted trials. The same was true of the comparisons between the subjects’ sprint-resistant and untethered trials.

**Differences in Wrist Flexion and Hyperextension: (Tables 8 and 9)**

Five of the six subjects flexed their wrists more during the insweep in both their sprint-assisted and sprint-resistant trials (see Table 8).

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Wrist angles in degrees</th>
<th>Untethered</th>
<th>Assisted</th>
<th>Resisted</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.K.</td>
<td>190</td>
<td>180</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>R.S.</td>
<td>183</td>
<td>175</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>P.W.</td>
<td>195</td>
<td>180</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>S.P.</td>
<td>180</td>
<td>142</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>M.L.</td>
<td>165</td>
<td>147</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>M.B.</td>
<td>173</td>
<td>177</td>
<td>165</td>
<td></td>
</tr>
</tbody>
</table>

The authors believe that the subjects’ tendency to flex their wrists to a greater extent through the middle of their armstrokes also indicates a shift toward drag-dominated propulsion. On film, they appeared to be flexing their wrists in an effort to achieve a greater backward angle of attack from the catch position through the insweep.

In the sprint-assisted trials, four of the subjects hyperextended their wrists to a greater extent during the final upsweep of their armstrokes (see Table 9). Four subjects exhibited less wrist hyperextension during their sprint-resistant trials.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Wrist hyperextension in degrees</th>
<th>Untethered</th>
<th>Assisted</th>
<th>Resisted</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.K.</td>
<td>40</td>
<td>22</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>R.S.</td>
<td>22</td>
<td>80</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>P.W.</td>
<td>25</td>
<td>12</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>S.P.</td>
<td>4</td>
<td>40</td>
<td>-7</td>
<td></td>
</tr>
<tr>
<td>M.L.</td>
<td>-5</td>
<td>22</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>M.B.</td>
<td>14</td>
<td>18</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

A minus (−) number indicates the wrist was flexed the indicated number of degrees.

The tendency to maintain their wrists in a more hyperextended position appeared to improve the subjects’ angles of attack during the upsweep in their sprint-assisted trials. Their hands were facing backward more and upward less. A view of the films showed that, for three of the subjects, the tendency to push upward against the water was reduced during this phase. On the other hand, the tendency to push upward appeared to increase during their sprint-resistant trials.

**Conclusions**

If, as some believe, increases in stroking power are speed specific, swimmers should equal or exceed competition stroke rates during swims against resistance. Sprint-resistant training caused the subjects in this study to take shorter, slower armstrokes.

Where sprint-assisted training is concerned, it is considered desirable for stroke rates to increase with no loss of stroke length. Although the subjects increased their stroke rates during the sprint-assisted swims, these increases were due primarily to reductions in stroke length rather than increases in hand velocity.

According to the transfer of training principle, increases in stroking power and swimming speed that may result from tethered swimming will be greater if the swimmers’ stroke mechanics closely simulate those of free swimming. The subjects in this study changed their stroke mechanics during both their sprint-assisted and sprint-resistant trials. Therefore, these results cast doubt on the efficacy of both sprint-assisted and sprint-resistant methods of training.

The swimmers tended to change their stroke patterns in ways that encouraged the use of drag propulsion rather than lift propulsion. They stroked downward less and backward more while also increasing the backward speed of their hands.

The amounts of elbow flexion were different during the sprint-assisted and sprint-resistant trials. There was no consistent direction to these differences, however.

Subjects tended to flex their wrist more during both the sprint-assisted and sprint-resistant trials. They also tended to hyperextend their wrists more during the final outward and upward sweep of their hands in the sprint-assisted trials.

These results could be considered an indictment of both sprint-assisted and sprint-resistant training methods. Their use might encourage swimmers to change their mechanics in ways that would make them less efficient. However, it is doubtful that such changes will occur if these methods comprise only a small part of the entire training program. In addition, there may be other benefits resulting from these types of training. Both may increase stroking power and although the increases may not transfer totally, the amount of transfer may be greater than could be achieved by other methods. The possibility also remains that these forms of training may increase untethered swimming speeds through other, as yet undiscovered, means.

The authors would like to mention that a qualitative analysis of the films showed that some of the subjects tended to improve their mechanics during their sprint-assisted trials. This was particularly true in those parts
of the stroke where faults had been noted during the untethered trials.

In conclusion, it can be said that swimmers change their mechanics during both sprint-assisted and sprint-resisted swimming. In many cases these changes encourage less efficient stroking. However, qualitative film analysis indicated that the subjects also improved certain aspects of their strokes during their sprint-assisted trials. This was particularly true of those with stroke defects.

References


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