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The relationship between vertical jump and reach performance and sprint speed in four swimming strokes

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THE RELATIONSHIP BETWEEN VERTICAL JUMP AND REACH PERFORMANCE AND SPRINT SPEED IN FOUR SWIMMING STROKES

by

Frederick W. DeBruyn

An Abstract

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of the requirements for the degree of
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ABSTRACT

This study examined whether significant relationships exist between vertical jump and reach performance (represented by both the height of the jump and a ratio composed of vertical jump height divided by the subject's height [jump height/height ratio]) and sprint speed in four different swimming strokes. Twenty-three Cornell University male varsity swim team members performed three trials of the vertical jump and reach and three trials of each of the four strokes. The jump and reach was measured to the nearest one-half inch and the sprints were measured to the nearest one-hundredth of a second. All trials of each test were administered on the same day. Intraclass reliability estimates, determined by analysis of variance, subjects by trials design, were determined to be acceptable for each of the tests administered. Significant negative Pearson product-moment correlations were determined between vertical jump and reach performance and each of the four strokes as well as between the jump height/height ratio and each of the four strokes. Therefore, the null hypotheses that there would be no significant correlations between either vertical jump and reach performance and each of the four strokes or the jump height/height ratio and each of the four strokes were rejected at the .05 level of significance. Since the results indicated that there were significant relationships between vertical jump and reach performance and sprint speed, a classification system for determining swimming performance was recommended.

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A Thesis Presented to the Faculty
of the School of Health, Physical
Education, and Recreation
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Master of Science

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by
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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

Frederick W. DeBruyn

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health, Physical Education, and Recreation at Ithaca College has been approved.

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Chapter 1

INTRODUCTION

For the past 50 years, coaches in most sports have been concerned with developing new types of training programs. This endless search for "something better" has not been without results. Many new ideas have proven to be useful and concepts such as interval training, repetitive training, progressive weight training, and the like have been developed (Counsilman, 1968).

One of the sports that has pioneered many of these new concepts, either by first conceiving them or by first employing them regularly, is swimming. Leaders in the swimming field, such as Counsilman, have contributed numerous ideas and theories on specific training methods. Interval and repetitive training, especially, have gained validity and widespread acceptance after they were shown to produce significant decreases in swimming times (Counsilman, 1968).

The problem is no longer merely how to train a distance swimmer or a sprinter; those solutions are becoming more and more obvious. The more taxing question is how to determine, more exactly, in which events a swimmer should be placed to make best use of his or her talents. Does the swimmer have more potential as a sprinter, a middle distance swimmer, or a distance swimmer? These are the questions that face the coach. The problem now is to find an accurate predictor of swimming ability.

Counsilman (1977) has suggested that a swimmer's performance on the vertical jump and reach test can be used to determine for which events he or she is best suited. Another possibility as an indicator may be a modification of Sargent's (1921) original efficiency index for his "physical test of a man." Instead of multiplying weight times jump height and dividing by the subject's height, the modification divides only the jump height by the subject's height to obtain a ratio (jump height/height ratio). This ratio might be more accurate than jump height alone because it takes the subject's size into account. Obviously, a person who jumps 60% of his or her own height is performing relatively better than one who jumps 40% of his or her own height regardless of the actual height of the jump.

Thus, the purpose of this study was to determine whether a significant relationship existed between vertical jump and reach height and sprinting speed in the four competitive swimming strokes, and whether a significant relationship existed between the jump height/height ratio and sprinting speed in the four competitive swimming strokes. A subproblem was to develop a classification method for swimmers based on their vertical jump and reach performance, or the jump height/height ratio, if a significant relationship did exist.

Scope of the Problem

Twenty-three volunteer male undergraduate students on the 1978-1979 varsity swim team of Cornell University, Ithaca, New York, were tested on performance in the vertical jump and reach and then timed for 25-yard sprints in the crawlstroke, backstroke, breaststroke, and butterfly. Each subject was given three trials in the vertical jump and reach as well as in each of the strokes. In order to ascertain maximum performance, the higher jump of trials two and three and the fastest sprint trial of each stroke were considered to be the criterion score (Counsilman, 1977; Smith, 1978). Tests were administered during the final week of the swimming season since it would be expected that the swimmers would reach their peak performance at that time. The jump height/height ratio was also compared to the criteria for the sprint tests. This ratio was a modification of Sargent's (1921) original proposal for his "physical test of a man." The criterion scores of each stroke were correlated with the criterion score of the vertical jump and reach and the jump height/height ratio using a Pearson product-moment correlation and the resulting r's were tested for significance.

Statement of the Problem

The intent of this study was to determine whether significant relationships exist between performance in the vertical jump and reach and sprint speed in the four competitive swimming strokes when vertical jump and reach performance is represented by the height of the jump and/or when it is represented by a jump height/height ratio.

Null Hypotheses

1. There will be no significant correlation between vertical jump and reach performance and sprint speed in the crawlstroke.

2. There will be no significant correlation between vertical jump and reach performance and sprint speed in the backstroke.

3. There will be no significant correlation between vertical jump and reach performance and sprint speed in the breaststroke.

4. There will be no significant correlation between vertical jump and reach performance and sprint speed in the butterfly.

5. There will be no significant correlation between the jump height/height ratio and sprint speed in the crawlstroke.

6. There will be no significant correlation between the jump height/

height ratio and sprint speed in the backstroke.

7. There will be no significant correlation between the jump height/height ratio and sprint speed in the breaststroke.

8. There will be no significant correlation between the jump height/height ratio and sprint speed in the butterfly.

Assumptions of the Study

The following were assumed in this study:

1. The subjects followed instructions to put forth maximum effort in each trial of the vertical jump and reach and the 25-yard sprints.

2. The subjects were instructed not to take part in any organized program of exercises or games during the duration of the study which would increase jumping ability other than those normally involved with swimming and therefore did not.

3. The weight training program used by the subjects as a regular part of their swimming training was not designed to improve jumping ability and therefore did not improve it.

Definition of Terms

The following terms were specifically defined for the purpose of this study:

1. Sprint speed. The amount of time it takes for the swimmer to touch the opposite end of the 25-yard pool after his feet leave the wall on the pushoff. Time is measured to the nearest one-hundredth of a second.

2. Vertical jump and reach height. The number of inches that a subject is able to propel himself above the ground doing a standing jump and reach. Height is measured to the nearest half-inch.

3. Strength. The maximum force exerted in a single, all-out

muscular effort (Åstrand & Rodahl, 1970).

4. Power. The maximum amount of strength which can be exerted in the shortest amount of time to accomplish a given task (Åstrand & Rodahl, 1970).

5. Sprinter. Swimmer who swims races of 50- to 100-yards in length.

6. Middle distance swimmer. Swimmer who swims races of 200- to 500-yards in length.

7. Distance swimmer. Swimmer who swims races of 500-yards or more in length.

Delimitations of the Study

The delimitations of the study were as follows:

1. The subjects were volunteer undergraduate male varsity swimmers attending Cornell University, Ithaca, New York, during the spring of 1979.

2. Five types of tests were used in this study: vertical jump and reach, 25-yard crawlstroke sprint, 25-yard backstroke sprint, 25-yard breaststroke sprint, and 25-yard butterfly sprint.

3. This study was concerned with vertical jump and reach height and the jump height/height ratio in relationship to swimming speed exclusive of starting and turning ability.

Limitations of the Study

The limitations of the study were as follows:

1. Since the vertical jump and reach and the jump height/height ratio data were correlated with swimming times, no cause and effect conclusion can be drawn from their relationship.

2. This study was not conducted in a completely controlled environment.

3. The swimmers involved did not normally compete in all of the

strokes being tested.

4. Since this was a specialized group which was not randomly selected, conclusions should not be generalized.

Chapter 2

REVIEW OF RELATED LITERATURE

Counsilman (1977) believes that the ability to produce power is one of the most important components which can be used to classify swimmers into different areas. Power producing ability has been shown to be related to the percentages of fast twitch fibers (FTFs) and slow twitch fibers (STFs) which an individual's muscles possess (Tesch, Sjödin, & Karlsson, 1978; Thorstensson, Larsson, Tesch, & Karlsson, 1977). The higher the percentage of FTFs, the greater the ability of the athlete to participate in short, all-out, anaerobic bouts. The higher the percentage of STFs, the greater the ability to participate in long, endurance-type bouts. The basic distribution of fiber percentages in an individual's muscles seems to be genetically determined (Thorstensson, 1977). However, studies have shown that fiber percentages may be altered to a small degree by specific training methods (Anderson & Henricksson, 1977; Costill, 1978; Jansson, Sjödin, & Tesch, 1978). It would follow that a swimmer with a high percentage of FTFs would be proficient in sprint events (Golnick, Armstrong, Saubert, Piehl, & Saltin, 1972; Prince, Hikida, & Hagerman, 1976) while one with a high percentage of STFs would be proficient in endurance type events (Costill, Fink, & Pollock, 1976; Nygaard & Nielson, 1978).

Since power producing ability is considered one of the most important requirements for success in sprinting events, Counsilman selected the vertical jump and reach as a test of that ability. The vertical jump and reach has been used as a test of power by many investigators (Chui, 1950; Considine, 1970; Considine & Sullivan, 1973; Huffman & Berger, 1972; Smith, 1961). Since a sprinter should possess more power, he or she should be able to jump higher than a middle distance swimmer, and a middle distance swimmer should be able to jump higher than a distance swimmer. Counsilman (1977), therefore, has developed vertical jump performance ranges for each group. Sprinters should be able to jump 24 to 31 inches, middle distance swimmers 18 to 25 inches, and distance swimmers 11 to 22 inches. The overlaps in the ranges occur because of the changeability of muscle fibers with different types of training (Anderson & Henricksson, 1977; Costill, 1978; Jansson et al., 1978). Therefore, it is possible that swimmers who score in the border areas could be good in either category (sprinter or middle distance and middle distance or distance).

The review of literature related to this study will, therefore, focus on the following areas: (a) Muscle fiber composition and changeability, (b) Relationship of fiber type to strength and endurance, (c) Relationship of fiber composition to proficiency in athletic events, (d) Relationship of power to vertical jump, (e) Relationship of power to strength, (f) Relationship of strength to swimming speed, and (g) Summary.

Muscle Fiber Composition and Changeability

Different types of muscle fibers (I, IIA, and IIB) were originally identified in lower mammals (Peter, Barnard, Edgerton, Gillespie, & Stempel, 1972; Stein & Padykula, 1962). Brooke and Kaiser (1970) attempted to determine if these fiber types are also present in man. Muscle biopsies were taken and stained to reveal the kinds of enzymes contained in the fibers. Fibers containing a low amount of the enzyme ATPase and high amounts of the enzyme succinic dehydrogenase (SDH) are classified as STFs (type I). These fibers are highly oxidative in the nature of their enzymatic activities and are more suited for aerobic types of work. Fibers containing a high amount of ATPase and a high amount of SDH are classified as FTFs A (type IIA). These fibers are oxidative and glycolytic in nature and are used in both aerobic and anaerobic activities. Finally, fibers containing high amounts of ATPase and low amounts of SDH are classified as FTFs B (type IIB). These fibers are highly glycolytic in nature and are used for anaerobic work.

In support of this, Sjögaard, Houston, Nygaard-Henson, and Saltin (1978) investigated whether the subgroups of FTFs could be reliably identified. Muscle biopsies were taken from four untrained men, 11 untrained women, and four well-trained women. Cross sections were stained for ATPase, NADH-D, and γGP-D. Two different fiber types, A and B, were identified by the stain intensity.

Recent findings, however, have postulated the existence of another type of FTF. In 1976, Prince et al. identified a third type of FTF which they called transitional. Muscle biopsies were taken from the vastus lateralis of trained (power lifters and distance runners) and untrained subjects. These transitional fibers were identified as containing high amounts of ATPase and moderate amounts of SDH in both the trained and untrained subjects.

Again, in 1977, Prince et al. investigated muscle fiber types in women athletes and non-athletes. Five collegiate field hockey players and five untrained female students had muscle biopsies taken from the vastus lateralis. When the samples were stained, the fiber types were classified according to their stain intensities. The fast twitch transitional fiber was found only in the athletes. The athletes also had a significantly greater ($p < .025$) number of IIA fibers indicating that they recruited a high percentage of fast twitch motor units frequently.

Additional support for the third type of FTF has come from Jansson, et al. (1978). The investigators tested four distance runners for fiber distribution changes after an 18 week aerobic and an 11 week anaerobic training program. Muscle biopsies were taken before and after the training periods and analyzed for fiber composition. They also identified a third type of FTF which they called IIC. The type IIC fiber was found to be present as only 1% of the total fiber distribution after the aerobic training period. After the anaerobic period, IIC fibers increased significantly ($p < .01$) to 12% of the distribution. At the same time, the STF distribution declined from 69% to 52%, a significant ($p < .05$) decrease. They concluded that there was a possible change between fiber type I (STF) and fiber type IIC depending upon the type of training in which the subject participated.

The changeability of muscle fiber types due to exercise has become a topic of great interest in the past few years. As was mentioned in the previous paragraph, Jansson et al. (1978) found significant changes in the STF ($p < .05$) and FTF C ($p < .01$) distributions after periods of aerobic and anaerobic training.

Anderson and Henricksson (1977) also found changes in fiber type after a program of endurance training. Twelve healthy male volunteers, aged 20 to 23, were trained in an eight week program on the bicycle ergometer. The subjects trained 30 minutes a day, four days a week, at an average work intensity of 81% of their maximal oxygen consumption ($\dot{V}O_2$ max, a common estimate of aerobic fitness). Muscle biopsies were taken from the vastus lateralis before and after the program. The biopsies were stained and fibers were divided into types (I, IIA, and IIB) depending upon the intensity of the stains. The pretraining distributions were: type I, 41%; type IIA, 37%, and type IIB, 19%. The posttraining distributions were: type I, 43%; type IIA, 42%; and type IIB, 14%. The results showed that there was a significant ($p < .05$) increase in the amount of IIA fibers and a significant ($p < .05$) decrease in the amount of IIB fibers. The investigators concluded that the type IIB fibers convert to type IIA during endurance training.

Costill (1978) tested male subjects on a seven week training program. One of the subject's legs was trained on six second isokinetic bouts while the other was trained with 30 second isokinetic bouts. The volume of work for both legs was equal (approximately 1650 kg × m/day) and the subjects trained four days per week. Biopsies were taken from the vastus lateralis of both legs before and after the training period. The pretest fiber distributions were: type I, 46.5%; type IIA, 29.2%; and type IIB, 24.2%. The posttest distributions were: type I, 38.8%; type IIA, 33%; and type IIB, 23.5%. Although none of these changes were statistically significant, there was a significant

($p < .05$) change in the percentage of fiber area in both legs. The change was approximately equal in each leg. The type I area declined from 42.1% to 35.7% and the type IIA area increased from 32.7% to 40.9%.

Contrary to these findings, however, Golnick, Armstrong, Saltin, Saubert, Sembrowich, and Shepard (1973) found no change in the fiber composition after a five month training program. Six male subjects were required to peddle a bicycle ergometer one hour a day, four days a week, at a load requiring 75% to 90% of the subjects' $\dot{V}O_2$ max. The results indicated a 13% increase in mean oxygen uptake, an increase in oxidative potential in both type I and II fibers, and an increase in the glycolytic capacity of type II fibers only. There was no change in fiber composition, however. The investigators concluded that this type of training caused an increase in the metabolic characteristics of the muscle but not in the fiber distribution.

Thorstensson, Hulton, Von Dobeln, and Karlsson (1976) studied the effects of an eight week strength training program on the fiber characteristics and enzyme activities of 14 male physical education students. The subjects were required to perform three sets of six repetitions of squats with near maximum work load, three times a week. Muscle biopsies were obtained from the vastus lateralis and measurements were taken in a series of functional tests (one maximal strength repetition, the Sargent or vertical jump and reach, standing broad jump, and a single maximal voluntary contraction) before and after the training period. Posttest results showed a significant ($p < .0001$) improvement in all of the functional tests but no significant changes in muscle size or fiber area.

To summarize, the literature seems to support the view that human skeletal muscle is composed of three distinct types of fibers: slow twitch (type I), fast twitch A (type IIA), and fast twitch B (type IIB). The possibility of a third type of fast twitch (IIC) which is a transitional fiber between either type I and type IIA or types IIA and IIB has been postulated in recent studies. Finally, study results support the view that muscle fiber distribution changes with different types of training.

Relationship of Fiber Type to Strength and Endurance

Tests of animal muscles have shown that those with a high percentage of FTFs have greater maximal contraction speeds, produce more force per contraction, deplete glycogen stores more quickly, and produce more lactate than those with a high percentage of STFs (Kugelberg, 1973). Inquiries concerning whether the same is true of human skeletal muscle have been made by many investigators in the past few years.

Karlsson (1973) investigated the relationship between isometric tension and glycogen depletion patterns in human skeletal muscles to obtain information about the type of fibers used at different tensions. Biopsy samples were taken from the vastus lateralis muscle of subjects at rest, during, and after isometric bouts. The tensions ranged from 10% to 40% of maximal voluntary contraction (MVC) strength of the knee extensors (vastus lateralis) with the knee at a 90° angle. Results showed that at tensions below 20% of MVC, glycogen depletion occurred in the STFs but at tensions above 25% MVC, the FTFs were the only fibers depleted of glycogen. It was concluded that at high tensions, FTFs are primarily recruited for work.

Tesch and Karlsson (1978) used the same type of testing apparatus to test maximal isometric leg strength and muscle fiber distribution in 31 male physical education students. Muscle biopsies were taken from the subjects' vastus lateralis muscles a few days before the tests and immediately after them. Significant correlations were found between muscle fiber distribution and maximal isometric strength ($r = .86$, $p < .01$). The authors concluded that muscles with a high percentage of FTFs are better adapted to the development of high tensions than those with high percentages of STFs.

Conversely, Hulton, Thorstensson, Sjödin, and Karlsson (1975) found no significant relationship between maximal voluntary isometric contraction and muscle fiber composition. The test device they used was very much the same as the ones used in the preceding two studies. Nineteen male physical education students each sat in an immovable chair and with the knee at a 90° angle, pushed against an immovable bar beneath the foot. Tests for MVC were performed on two consecutive days and a test at 50% of MVC was performed on a third. Biopsies were taken from the vastus lateralis on one of the first two days. A relationship was found between 50% MVC endurance time and fiber composition. The conclusion drawn was that the ability to sustain isometric endurance time was related to the percentage of STFs that serve as a lactate recipient for the FTFs.

Thorstensson, Grimby, and Karlsson (1976) investigated the relationship between force-velocity production and muscle fiber composition in isokinetic knee contractions. Twenty-five healthy male subjects were each attached to a Cybex II isokinetic knee dynamometer and performed leg extensor contractions throughout a 90° range (to full extension). Biopsies were taken from the vastus lateralis of the tested leg after the work bouts. The results showed that at any given angle of the knee, the torque produced for isometric contractions was higher than that produced for dynamic contractions. Significant correlations ($p < .05$) were found between peak torque produced at the highest speed of muscle contraction and percent of FTFs as well as relative area of FTFs. Additionally, muscles with high percentages of FTFs had the highest maximal contraction speeds.

In 1977, Thorstensson arrived at similar conclusions through a series of four experiments. The object of these experiments was to investigate the relationship between the contractile properties of the muscle (force-velocity and fatigability) and the "quality" of the muscle in terms of fiber composition. Different numbers of subjects were used in the experiments, three of which involved habitually active men, and one which involved world class athletes in different areas (sprinters and jumpers, cross-country skiers, competitive walkers, and downhill skiers). The testing apparatus was the Cybex II isokinetic dynamometer and all measurement was done on the subjects' left legs. Strength was measured as maximal torque output in a 90° range of motion. Fatigue was assessed by the reduction of maximal strength in a series of 50 maximal contractions of the leg extensor muscles done in one minute on one day and 100 maximal contractions (50/min) on a second day. The author found a significant positive correlation ($r = .73$, $p < .05$) between peak force output and percentage of FTFs in muscle biopsies taken from the vastus lateralis muscle. Susceptibility to fatigue was also found to be related ($r = .86$, $p < .01$) to percentage of FTFs. Finally, world class sprinters and jumpers were found to have a significantly higher fast to slow twitch fiber percentage ratio than both sedentary men and endurance athletes.

Using the same experimental setup as in the previous two studies, Thorstensson and Karlsson (1976) tested the fatigability of human skeletal muscle in relation to its fiber composition. Ten active male subjects performed 50 contractions of the leg extensor muscles per minute on the Cybex II dynamometer. Fatigue was expressed as the mean decline in peak muscular force from the first to the last contraction. The results showed a high positive correlation ($r = .86$, $p < .01$) between percentage of FTFs and fatigue.

Also arriving at similar conclusions were Tesch, Sjödin, Thorstensson, and Karlsson (1978). They tested nine males, twice in one week on the Cybex II. The subjects performed 50 leg extensions per minute during the first session and 20 per minute during the second. Analysis of biopsies taken from the vastus lateralis of the exercised leg indicated that initial strength and decline in peak torque after 50 extensions (fatigue) significantly correlated with both the distribution percentage of FTFs ($r = .88$, $p < .001$) and the relative area occupied by FTFs ($r = .94$, $p < .001$). The conclusion reached was that FTFs have high fatigue factors and accumulate more lactate. Consequently, muscles with high percentages of FTFs will have high fatigue factors.

Again in 1978, Tesch, Sjödin, and Karlsson investigated the relationship between lactate accumulation, enzymatic activity, and fiber composition in human skeletal muscle. The experimental apparatus used in the four previous studies was also employed in this study. Subjects were required to perform 25 maximal isokinetic leg contractions of the leg extensors on the Cybex II. Analysis of muscle biopsies taken from the vastus lateralis immediately following the work bouts showed a high positive correlation ($\underline{r} = .91$, $\underline{p} < .001$) between FTF percentage and lactate accumulation. The lowest amount of lactate accumulation occurred in the subject with the highest amount of STFs. The conclusion reached was that the FTFs produced more lactate than STFs.

Approaching the problem from a different angle, Golnick, Sjödin, Karlsson, Jansson, and Saltin (1974) analyzed biopsies from the soleus and either the gastrocnemius or the vastus lateralis of nine male and two female subjects. The results showed that the soleus contained a combined average of 80% STFs in comparison with the gastrocnemius' and the vastus lateralis' combined average of 57%. From the enzymatic properties present in the muscles, the authors concluded that the STFs possess a lower glycolytic potential than the FTFs.

Also using this type of analysis were Thorstensson, Sjödin, Tesch, and Karlsson (1977). Muscle biopsies obtained from the vastus lateralis of two healthy male subjects were analyzed for their fiber composition and enzymatic properties. The results indicated that there was a more pronounced anaerobic glycolytic potential in FTFs and a higher capacity for lactate combustion in STFs. The conclusions drawn were that the metabolic profile of FTFs was more in favor of fast contractions and rapid ATP replenishment while the STFs have greater potential for aerobic metabolism and slower contractions.

In summary, the evidence seems to support the contention that fast twitch muscle fibers have greater glycolytic anaerobic potential, produce more force per contraction, have higher contraction speeds, form more lactate, and have less endurance than slow twitch muscle fibers.

Relationship of Fiber Composition to Proficiency in Athletic Events

A number of studies have also been done to determine the fiber composition of the muscles of accomplished athletes. In most cases, they have been done in a comparison with subjects of lesser accomplishments in an attempt to identify the differences between the two.

In 1976, Costill et al. studied the muscle fiber composition and enzyme activities of 14 world class distance runners, 18 highly trained middle distance runners, and 19 untrained men. Muscle biopsies taken from the gastrocnemius were analyzed. The results showed that the world class runners were characterized by a very high percentage (79%) of STFs. The average cross-sectional area of the world class runners' STFs was 29% ($p < .05$) greater than that of their FTFs. In contrast, the cross-sectional areas of the middle distance runners were about equal, while those of the untrained men showed a slightly greater fast twitch area. Oxidative enzymatic activities were significantly greater in both the world class and middle distance runners than in the untrained men.

Nygaard and Nielson (1978) took biopsies from the rectus femoris, middle deltoid, and lattisimus dorsi of 14 male and 11 female competitive distance swimmers, ranging in ability from national to world class levels. All swimmers had had at least five years of intensive training in middle distance or distance swimming. The biopsies were stained and classified as to fiber composition and compared to biopsies taken from a control group of 69 untrained males and 25 untrained females. Results of the comparisons revealed that in all three muscles, the trained swimmers had a significantly ($p < .001$) greater percentage of STFs than did the control. In the case of the upper body muscles, no fast twitch B fibers (high glycolytic) were found as compared to 15% to 20% for the control group.

Prince et al. (1976) compared muscle samples from the vastus lateralis of three distance runners, five power lifters, and five untrained controls. The results showed that the distance runners had a significantly lower percentage of FTFs B (highly glycolytic) than either the controls ($p < .005$) or the power lifters ($p < .001$). Both the runners ($p < .01$) and the controls ($p < .02$) had a significantly greater amount of FTFs A (oxidative glycolytic) than did the power lifters. A significant ($p < .01$) trend was found towards more oxidative fibers in the runners and more glycolytic fibers in the lifters. These results are in general agreement with Nygaard and Nielson (1978).

Golnick et al. (1972) analyzed biopsy samples from the vastus lateralis and deltoids of a total of 74 trained and untrained subjects. The investigators found that the percentage of FTFs and STFS differed by age, degree of training, and muscle group. There were, however, wide differences in the fiber composition of highly trained athletes in different sports. World class cyclists averaged about 60% STFs and cross-country runners averaged about 75% STFs. In contrast, a 9.3 second 100-yard sprinter had only 26% STFs (74% FTFs). On the average, the trained subjects had a significantly higher oxidative capacity than the untrained men.

Komi, Rusko, Vos, and Vihko (1977) studied the anaerobic performance characteristics of the whole body in 89 athletes and 31 control subjects. The main tests administered were an upstairs run to test vertical velocity, blood lactate accumulation after maximal treadmill running, percentage of FTFs, lactate dehydrogenase, and creatine phosphokinase activity in the vastus lateralis. Results tended to divide athletes into either anaerobic or aerobic categories with certain characteristics required for successful performance. It was concluded that the main characteristics which described the anaerobic performance capacity of the body were related to percentage of FTFs and that a high percentage of FTFs might be a prerequisite for success in anaerobic (power) events.

Finally, Thorstensson, Larsson, Tesch, and Karlsson (1977) tested muscle strength and fiber composition in 29 members of Swedish national teams (9 sprinters and jumpers, 6 downhill skiers, 7 race walkers, and 7 orienteers) and 10 sedentary men. Muscle biopsies were taken from the vastus lateralis and muscle strength was measured as the peak torque of isokinetic knee extensions of the Cybex II dynamometer. The results showed that the percentage of FTFs of the sprinters and jumpers (61%) was significantly ($p < .05$) higher than that of the race walkers (41%) and orienteers (33%). The sprinters' and jumpers' cross-sectional FTF area was 50% greater than their STF area. This ratio was significantly greater ($p < .05$) than that of orienteers and sedentary men. Lastly, at highest velocity, the sprinters and jumpers produced significantly greater ($p < .05$) peak torque than the other groups. A significant correlation ($r = .48$, $p < .01$) was found between relative torque output and FTF area.

To summarize, athletes in power events seem to be characterized by having muscles with a high percentage of fast twitch muscle fibers while those in endurance events have a high percentage of STFs and, in some cases, an almost complete absence of fast twitch B (high glycolytic) fibers.

Relationship of Power to Vertical Jump

Power has been defined as the maximum amount of strength which can be exerted in the shortest amount of time to accomplish a given task (Åstrand & Rodahl, 1970). Many studies have attempted to use different tests (shotput, sprints, broadjumps) to measure power. One of the best of these tests is the vertical jump and reach.

The vertical jump and reach was first introduced by D.A. Sargent (1921) as his "physical test of a man." Originally, Sargent used performance in the test to establish an "efficiency index" which was actually a rough estimation of power. Since it was introduced, it has been variously described as a test of leg power (Considine, 1970; Considine & Sullivan, 1973), relative leg power (Huffman & Berger, 1972), explosive leg power (Smith, 1961), and athletic power (Chui, 1950).

Three studies have approached the problem of analyzing the contributing components of the vertical jump and reach. Bangerter (1968) had four experimental groups train with weights three times a week for 8 weeks for specific muscle groups (plantar flexors, knee extensors, hip extensors, and all of the preceding) to identity which groups were most involved in jumping. Pretest and posttest trials were given to the four groups plus a control and the data were subjected to ANCOVA. Results showed significant increases in the groups which trained the hip and/or knee extensors indicating that these groups were the ones mostly used in the actual jump itself.

Aldritch (1958) came to similar conclusions in a study designed to determine if knee bends and heel raises increased vertical jump and reach. An experimental group trained with weights three times a week for 6 weeks. Both the control and experimental groups were given pretests and posttests in the vertical jump and reach. The experimental group showed a significant (p < .01) increase of 2.1 inches in the posttest. It was concluded that the extensor muscles are important to vertical jump and reach performance but the plantar flexors contribute little.

Luthanen and Komi (1978) approached the problem in a different manner. They tested eight male athletes on their performance in two vertical jumps as well as seven different movements on a force platform. Both cinematographic and force platform techniques were employed to analyze the contributions made by different body segments to the total jump. The results, although in general agreement with Bangerter and Aldritch, indicated that plantar flexion was responsible for 22% of the force generated, a rather significant amount.

Many observers have felt that the vertical jump and reach was not a true test of leg power since it allows the subject to use his or her arms while performing it. Because of this, a number of studies have attempted to develop a better method for determining leg power. Glencross (1960) developed a modification of Sargent's jump which he called the vertical power jump. In this test the center of gravity of the subject was determined and its height was measured in three different positions (squatting, tiptoe, and at the apex of a jump). When the subject performed the jump, he or she was not allowed the use of his or her hands. Power was determined algebraically from the subject's weight and the three measured heights.

Grey, Start, and Glencross (1962a) used this type of measurement on 80 subjects and concluded that it was a genuine test of the power developed by the legs in the vertical jump. They realized, however, that the complications of determining the subject's center of gravity made the vertical power jump difficult, if not impractical, to administer to a large group. Therefore, they developed a more practical modification of it and tested it along with the vertical jump and reach, standing broad jump, and the squat jump against the vertical power jump for reliability and validity (Grey, Start, and Glencross, 1962b). Eighty male students were tested and the maximum height of three attempts was used as the criterion score. Based on Pearson product-moment correlations with the vertical power jump, the modified power jump was determined to be both the most reliable and the most valid expression of power, with *r*'s of .977 and .989 for reliability and validity, respectively, as compared with values of .950 and .650 for the vertical jump.

In opposition to the feeling that the vertical jump and reach is not a true test of leg power, Van Dalen (1940) concluded that the Sargent jump was a valuable test of leg power when it was administered correctly. A problem with these results is that none of the tests used by him took body weight into consideration. Huffman and Berger (1972), however, managed to give Van Dalen's findings some support. They tested 50 college subjects to determine whether relative or absolute leg power was a better predictor of physical performance. The vertical jump and reach was used as a measure of relative leg power while a modified leg power test was used for absolute leg power. The subjects were also tested on Barrow's Motor Ability Test and the AAHPER Youth Fitness Test. The data were correlated and the resulting Pearson r's (with Barrow's and AAHPER Tests, respectively, .730 and .430 for the vertical jump and reach and .670 and .480 for the leg power test) showed that there was no significant difference between relative and absolute leg power as predictors of physical performance. The nonsignificant difference between the two power tests also indicated that the vertical jump and reach was a good indicator of leg power.

Considine (1970) found a moderate relationship between power and the vertical jump and reach. He analyzed the validity of a number of leg power tests: vertical jump and reach, standing broad jump, chalk board jump, 5-yard sprint, 10-yard sprint, and a 5-yard sprint with a 5-yard running start. These tests were performed by 105 subjects along with a criterion power test of a modified vertical jump and reach from a force platform. Power was determined by means of a derived equation which used data from the force platform.

Validity was determined by product-moment correlations. Findings showed that the vertical jump and reach had the highest coefficient ($\underline{r}$ = .508) of all the power tests.

Opinions vary greatly concerning the number of trials which should be used to score the vertical jump and reach. Henry (1959) found a reliability coefficient of .880 using three trials. This coefficient rose to .970 when 10 trials were used. Glencross (1960), however, found an $\underline{R}$ of .950 using only three trials. Considine administered six trials and obtained an intraclass coefficient of .989 using trials 3 through 6. Both Herman (1976) and Parcells (1977) administered five trials. Herman obtained an intraclass coefficient of .986 using trials 2, 3, and 4, while Parcells found a .992 on trials 2 through 5. Counsilman (1977) has recommended three trials. It can be seen from the preceding results that there is no real agreement on the number of trials which should be administered.

In summary, researchers have used a great number of tests (standing broad jump, 5-, 10-, and 60-yard sprints, 8 and 12 pound shotputs, and the chalk board jump) in attempting to measure power. Some (Glencross, 1960; Grey et al., 1962b) have even developed their own methods. However, the vertical jump and reach has consistently shown to be one of the best and easiest to administer.

Relationship of Power to Strength

Early studies into the relationship of power and strength revealed only low correlations. Harris (1937) studied the relationship between the two using the vertical jump and reach, the standing broad jump, the 40-yard dash, the basketball throw, and the shotput as measures of power. Both back lifts and leg lifts were used to determine strength. Relationships between the two were determined by means of Pearson product-moment correlations. The results showed r's ranging from .194 to .628 between power and strength. Specifically, she found a correlation of .215 between general leg strength and the vertical jump and reach.

Smith (1961) attempted to determine the relationship between explosive leg strength, which he measured by means of a leg dynamometer, and performance in the vertical jump and reach. A total of 70 male students were tested for leg strength as well as on a vertical jump and reach which was modified by forbidding any arm movement. A low, nonsignificant Pearson r of .199 was interpreted to mean that strength exerted against a dynamometer involved a different neuromuscular pattern than strength exerted by the muscles during a jumping movement.

Later studies have revealed a somewhat higher relationship between power and strength. A study done by Considine and Sullivan (1973) revealed low to moderate correlations. The study used a criterion of a modified vertical jump and reach on a force platform as well as six leg power tests: vertical jump and reach, standing broad jump, chalk board jump, 5-yard sprint, 10-yard sprint, and 5-yard sprint with a 5-yard running start. Strength of hip and knee extension and plantar flexion was measured by means of a cable tensiometer. Power was determined algebraically by means of an equation derived from the force platform data. The arms were not allowed to be moved, in order to obtain an accurate reading of leg power. The highest correlation obtained was a .50 for the vertical jump and reach. The authors concluded that strength and power do not seem to bear a high relationship to each other.

McClements (1966) obtained slightly higher values. The object of the study was to determine the relationship between power and the strength of leg and thigh flexor and extensor muscles. In addition, the effects of strength development of those muscle groups on power were also examined. Pearson product-moment correlations revealed r's of .520 between flexion strength and power and .620 between extension strength and power. Gains in strength after a training period, however, were not significantly related to gains in power.

Berger and Henderson (1966) found similar results when they examined whether static or dynamic leg strength was more related to power. The investigators used a dynamometer to measure static strength and a maximal squat lift was used to measure dynamic leg strength. A modified vertical jump and reach was used to measure power. Pearson product-moment correlations revealed r's of .710 between power and dynamic strength and .640 between leg power and static strength. The authors concluded that both static and dynamic leg strength were moderately related to leg power but neither was more related to power than the other.

The more recent studies differ from the findings of earlier ones. This is probably because Harris (1937) and Smith (1961) used jump height only as a measure of power. The more recent studies multiplied the subject's jump height by his or her weight to measure the amount of work done. Berger and Henderson (1966) also tried to analyze this problem in their study. They correlated the strength scores with the amount of work accomplished and found an r of .640 which compared very favorably with the .350 when strength was correlated with height only.

A number of studies have dealt with the relationship between leg strength and leg power as measured by the vertical jump and reach. Chui (1950) investigated the effects of systematic weight training on selected events of athletic power. Two groups ($\underline{N}_1$ = 23, $\underline{N}_2$ = 22) engaged in either weight training or a required physical education program. Pre- and post-training measures were taken on seven tests: vertical jump and reach, running vertical jump, standing broad jump, 8 and 12 pound shotputs, and a 60-yard dash. Results showed that the weight training group improved in every test while the physical education group did not. Based on these results, Chui concluded that increases in strength are accompanied by increases in power.

Subsequently, Berger (1963) tested 89 male college students in different training programs to determine the effects of static and dynamic training on vertical jumping ability. The subjects were divided into four different groups, two of which trained with different dynamic weight programs, a third trained with a static weight program, while the fourth trained by vertical jumping. Pre- and post-training tests of vertical jump and reaches were administered to all groups. ANOVA revealed that there was no significant difference between the two dynamic training groups but both improved significantly more than those which had trained statically or just by jumping alone. The investigator concluded that strength gain significantly improves vertical jump and reach height and that dynamic training improves it the most.

Darling (1961) also found that weight training improves vertical jump and reach performance. Subjects were given a five week training period of heel raises and deep knee bends. Posttests revealed significant ($p < .01$) increases of 1.65 inches for the heel raise group and 2.1 inches for the knee bend group. The investigator concluded that both weight exercises increase vertical jumping ability but neither is superior to the other.

Parcells (1977) examined the effects of depth jumping and weight training on vertical jumping ability. Forty-five male subjects were randomly assigned to weight training, depth jumping, or control groups. Subjects were tested on the vertical jump and reach before and after a six week training period. During this period, the two experimental groups underwent a progressive weight training program or a depth jumping program two times a week. ANOVA revealed that although there was an increase in both of the training groups only the depth jumping group improved significantly.

To summarize these findings, strength has been shown by investigators to have a low to moderate correlation with power. It has also been shown, with some exceptions, that increases in strength produce increases in both power and vertical jump and reach performance.

Relationship of Strength to Swimming Speed

Although a large number of studies have dealt with the relationship between strength and speed of movement in general, relatively few have been done about strength and swimming speed. Of those which have examined swimming speed, most have dealt only with the crawlstroke. Still, there have been enough studies in the past 15 years to allow some insight into the problem.

Jensen (1963) examined the effect of five different combinations of swimming and weight training on speed of the front crawl of 60 subjects. Initial and final times were taken on two days with the subjects performing one 40- and one 100-yard sprint with 20 minutes rest in between on each day. Times for each distance were averaged to determine an initial and a final criterion. Each group participated in a 6 week training period consisting of different combinations of weight and swimming training. The results revealed that all five groups significantly improved performance in the 100-yard swim, $t\ (11) = 3.111$, 2.782, 3.183, 2.933, and 3.209, $p < .05$, for groups 1 through 5, respectively. However, only group 5 (swimming and weight training every day) significantly improved on the 40-yard swim, $t\ (11) = 2.831$, $p < .05$. It was concluded that all workout combinations produced increases in speed in the 100-yard swim, but only a combination of daily swimming and weight training produced significant increases in 40-yard swimming speed.

In 1967, Scott tested the effect of isometric and elastic cord exercises on strength and speed of swimming. The investigator tested two experimental groups (one performing isometric exercises, the other elastic cord exercises) and one control group on a 6 week training session after timing them both on 25- and 50-yard crawl sprints. After the 6 weeks, subjects were tested each week of both training sessions. Results showed significant improvements in both strength and swimming speed for both types of training.

Gregor (1974) also reported similar findings when testing the effect of a progressive weight training program on the performance of the 100-yard crawl by 40 male and female swimmers. Pre- and post-training tests in the 100-yard crawlstroke and 16 strength measures were given to the subjects around a 9 week training program. During this time, half participated in a competitive swimming training program and a weight training program, while half only participated in the swimming training program. Results demonstrated that the weight training group improved in strength in all 16 measures, significantly in seven of them. The weight training group also improved significantly in the 100-yard crawlstroke while the control group did not. It was concluded that increases in strength were accompanied by increases in swimming speed.

In partial agreement with the previous studies were Ross' (1970) findings. Seventy-two subjects performed three 25-yard sprints with their legs tied. The mean of the three times was considered the criterion score. The subjects were divided into four groups and performed weight training and Exer-genie exercises three days per week for 6 weeks. A posttest was administered following the same procedures as the pretest. The t values indicated significant gains by all groups in strength and swimming speed. However, Pearson r's showed that only one out of four groups (the swimming only group) showed a significant correlation between improvements in strength and speed.

In opposition to the previous studies, two investigators, Ainsworth (1970) and Bestor (1972), found no relationship between swimming speed and strength. Ainsworth tested the effectiveness of isometric resistance training on strength of arm flexion and knee extension and speed of swimming. After a pretest of 50-yard swims and strength measurement on a tensiometer, both the control and experimental groups took part in a 6 week training period consisting of regular swimming workouts. The experimental group also participated in two daily exergenic workouts. ANOVA showed that there were no significant gains in either strength or swimming speed by either of the groups.

Bestor (1972) tested 20 college males on two training programs, one involving only interval swimming and the other involving interval swimming augmented by a progressive isotonic weight program. Pre- and post-training measures consisted of 50-yard sprint times in three competitive strokes (crawlstroke, backstroke, and breaststroke). ANOVA showed that after 8 weeks of training, no significant differences occurred in any of the swimming times although significant gains were registered in four weight exercises.

To summarize, the findings of the investigators tend to support a positive relationship between strength and speed of swimming. Most investigators have measured speed over distances of 50 yards or less and evidence indicates that speed increases as strength increases.

Summary

Human muscle tissue has been shown to be composed of at least three types of muscle fibers, slow twitch (type I), fast twitch A (type IIA), and fast twitch B (type IIB). STFs are highly oxidative in the nature of their enzymatic activity while FTFs B are highly glycolytic. FTFs A are a combination of both characteristics. Recent findings, however, have postulated the existence of a fourth type of fiber. This type is probably a transitional fiber between IIA and IIB and has been labeled IIC. The percentage of different fibers varies with the amount and type of training. With greater aerobic training, the type I and IIA percentages tend to increase while the IIB and IIC percentages tend to decrease. With greater anaerobic training, the opposite is true.

Because of their nature, different fiber types have different characteristics in regard to strength and endurance. Since type II fibers have a higher glycolytic potential than type I, they have higher contraction speeds and produce more force per contraction (therefore producing more power). Type I fibers possess more oxidative enzymes and mitochondria than type II fibers. Therefore, they accumulate less lactic acid and have more endurance than type II fibers. Studies of athletic proficiency in different events tend to support these characteristics. Athletes in power or strength events (weight throws, sprints) usually possess a high percentage ($\geq$ 70%) of FTFs while endurance athletes are usually found to have a high percentage of STFs. Middle distance athletes have approximately equal amounts.

Power is defined as the maximum amount of strength which can be exerted in the shortest amount of time to accomplish a given task. From its definition it can be seen that power is composed of two components, strength and speed. Many common tests such as the shotput, standing broad jump, chalk board jump, and short sprints have been used as measures of power. In addition to these, more accurate methods such as the vertical power jump have been developed.

Although strength is a component of power, attempts to establish the exact relationship between the two have had widely varied results.

Although most studies have found low to moderate values, correlations have ranged from .199 to .710. It would seem that the exact relationship of strength and power is quite hard to define.

The relationship between strength and swimming speed seems to be a little clearer. Studies have supported positive relationships between amount of strength and swimming speed and gains in strength and gains in swimming speed.

Chapter 3

METHODS AND PROCEDURES

This chapter deals with the following areas: (a) Selection of subjects, (b) Testing instruments, (c) Testing procedures and methods of data collection, (d) Treatment of data, and (e) Summary.

Selection of Subjects

The subjects (*N* = 25) were volunteer male undergraduate students at Cornell University, Ithaca, New York. All subjects were members of the Cornell University men's varsity swimming team during the 1978-1979 academic year and read and signed an informed consent form (Appendix A). All subjects were asked if they had taken part in any programs which contain extensive jumping exercises or in any sports (such as volleyball or basketball) where jumping is an integral part of the game. Since it was thought that participation in these types of activities might tend to increase jumping ability (Parcells, 1977) and thus bias the experiment, if any of the prospective subjects had answered in the affirmative, they would have been excluded from the study. No subjects were excluded from the study for this reason, but two were excused because of physical injuries which were suffered before the study took place.

Testing Instruments

Vertical Jump and Reach

The vertical jump and reach was administered to all subjects. The reason for the selection of this test was that it has been used by many investigators as a test of power and it is a criterion which has been used by Counsilman (1977) for the determination of sprinters, middle distance swimmers, and distance swimmers in the freestyle events.

Vertical Jump Scale

This scale was marked on a gray wall in black paint, starting at a height of seven feet above the floor and proceeding at one-half inch intervals to a height of 11 feet. The subjects chalked their fingers, so that when they touched the scale, white markings would remain. Markings were erased after every trial.

25-Yard Sprints

The 25-yard sprint was chosen as a test for sprinting abiliity because a longer test in a 25-yard pool involved the problems of acceleration, deceleration, and reaction time when the subject performed a turn. A second reason for choosing the 25-yard sprint was that it was thought that a longer event could involve a fatigue factor which detracted from actual top sprinting speed.

Timing Device

The timing device used throughout the testing was a three month old Cronus 2D electronic watch. The watch was certified by the manufacturer to be accurate to ±.001 of a second and was used to time all sprints for all subjects for consistency. All timing was done by the investigator who, at the time of the study, had had 12 years of experience in timing swimmers in competitive situations.

Testing Procedures and Methods of Data Collection

Vertical Jump and Reach Test

The subject stood facing a wall upon which a scale had been marked in half-inch intervals. While keeping both feet flat on the floor and toes touching the wall, the subject reached up with both hands as high as he could to determine his standing reach. Before taking the measurement, the investigator pressed between the subject's shoulder blades with his hand to insure that the subject was extending his arms as high as possible. The height reading was then taken to the nearest half inch. The subject was then instructed in how to do the vertical jump and reach (Appendix B) and practice trials were allowed until the subject felt comfortable in performing the action. When the subject felt he was prepared, he chalked his fingers and assumed a ready position which was comfortable for him. He was not allowed to make any preliminary foot movements, but was allowed to move his arms and bend his knees. When the subject was ready, he jumped and touched the scale at his maximum height. The investigator stood on a ladder next to the scale in order to record the height as accurately as possible. This height was also recorded to the nearest one-half inch. After each attempt, the chalk marks were erased. When all trials had been completed, the standing reach of the subject was subtracted from the recorded jump heights to determine the actual jump heights. The higher of trials two and three was considered the criterion score for the vertical jump and reach. Each subject was allowed three trials with 30 seconds rest between trials. All test trials were administered on the same day.

<u>25-Yard Sprint</u>

The subject was allowed as much time to warm up as he felt he needed since some people need more time than others to get ready to swim. When the subject was ready, he was instructed in what he was to do (Appendix C). He then assumed a comfortable starting position in the water at one end of the pool. On the command "Go," the subject pushed off the wall with both feet and began to sprint. As soon as the subject's feet left the wall, the investigator started the electronic stopwatch. As the subject swam the sprint, the investigator walked along the edge of the pool from the starting end to the finishing end. The investigator stopped the watch when he determined that the subject had touched the finishing end of the pool or had broken the vertical plane which extended above the end of the pool with any part of his body. Each subject performed three trials of each stroke in the same order: butterfly, backstroke, breaststroke, and crawlstroke. Each subject was given a minimum of 5 minutes rest between trials but was allowed more time if he felt he needed it. All times were recorded to the nearest one-hundredth of a second and the fastest of the three trials of each stroke was considered the criterion score for that stroke (Smith, 1978). All test trials were administered on the same day.

Treatment of Data

Intraclass reliability was calculated by the ANOVA technique as identified by Baumgartner (1969). The individual trial scores for the vertical jump and reach and four strokes were subjected to ANOVA, subjects by trials design. The data could be said to be trend free if the resulting F ratios for the trials were non-significant. If this is the case, then the data from all trials may be used to get a pooled error estimate for the reliability calculations.

The criterion scores for each stroke and the vertical jump and reach were subjected to the SPSS Pearson Corr program (Nie, Hull, Jenkins, Steinbrenner, & Bent, 1975) to determine the means and standard deviations. The subjects' criterion scores for the vertical jump and reach were then assigned into one of three categories (sprint, middle distance, or distance) depending upon what type of events the subject had primarily participated in during the season and means and standard deviations were calculated for each group. A ratio composed of vertical jump height divided by the subject's height (jump height/height ratio) was then calculated for each subject.

The criterion scores of the vertical jump and reach and the jump height/height ratio were then compared with the criterion score of each stroke using the SPSS Pearson Corr program. The resulting _r_'s were then tested for significance at the .05 level of significance.

Summary

A total of 23 volunteer male undergraduate varsity swimmers at Cornell University were tested on the vertical jump and reach and 25-yard sprinting performance in the four competitive strokes. Criterion scores were determined to be the higher jump of the last two trials and the fastest sprint in each of the four strokes.

Intraclass reliability was calculated by the ANOVA method. The individual trial scores were subjected to ANOVA, subjects by trials design.

The criterion scores for each stroke and the vertical jump and reach were subjected to the SPSS Pearson Corr program to determine the means and standard deviations. The subject's vertical jump and reach criterion scores were then grouped according to the events in which they had primarily swum during the season and the means and standard deviations for each group were also calculated. The criterion score for each stroke was compared to the criterion score of the vertical jump and reach and the jump height/height ratio using a Pearson product-moment correlation. The resulting *r*'s were then tested for significance at the .05 level of significance.

Chapter 4

RESULTS

This chapter deals with the following areas: (a) Reliability of data, (b) Descriptive analysis, (c) Pearson product-moment correlations, and (d) Summary.

Reliability of Data

The data across three trials were subjected to ANOVA, subjects by trials design, in accordance with Baumgartner's (1969) suggestion. An F ratio of 3.44 at the .05 level of significance was needed for a significant difference between trials. F ratios of .730 for the jump heights, 1.158 for the crawlstroke, 1.630 for the backstroke, 2.750 for the breaststroke, and 1.833 for the butterfly were obtained. It was concluded that there were no significant differences between the trials in any of the tests. Therefore, a pooled error estimate was obtained and an intraclass reliability estimate was calculated for each test. The results of these analyses may be found in Tables 1, 2, 3, 4, and 5.

Reliability was calculated by the ANOVA formula for intraclass correlation. Because the trial effect was not significant, a pooled error estimate was calculated by the ANOVA formula ($\underline{R} = \frac{\underline{MS}_S - \underline{MS}_E}{\underline{MS}_S}$) for each test. The reliability coefficient for the jump and reach tests was only .446. Therefore the first trial was eliminated and reliability was recalculated using trials two and three (Table 6). The resulting coefficient, .990, proved to be much more acceptable. Coefficients for the swimming strokes proved to be quite high (.994 for the crawlstroke, .830 for the backstroke, .931 for the breaststroke,

Table 1

Analysis of Variance for all Trials of the Vertical Jump and Reach

Source of Variation	*df*	*MS*	*F*
Subjects	22	34.793	
Trials	2	7.359	.730
Error	44	10.075	
Total	68	17.992	

Table 2

Analysis of Variance for all Trials of the Crawlstroke

Source of Variation	*df*	*MS*	*F*
Subjects	22	1.026	
Trials	2	.002	1.158
Error	44	.001	
Total	68	.333	

Table 3

Analysis of Variance for all Trials of the Backstroke

Source of Variation	df	MS	F
Subjects	22	4.134	
Trials	2	.007	1.630
Error	44	.004	
Total	68	1.340	

Table 4

Analysis of Variance for all Trials of the Breaststroke

Source of Variation	df	MS	F
Subjects	22	6.222	
Trials	2	.007	2.750
Error	44	.002	
Total	68	2.015	

Table 5

Analysis of Variance for all Trials of the Butterfly

Source of Variation	df	MS	F
Subjects	22	1.604	
Trials	2	.003	1.833
Error	44	.002	
Total	68	.520	

Table 6

Analysis of Variance for the Final Two Trials of the Vertical Jump and Reach

Source of Variation	df	MS	F
Subjects	22	24.624	
Trials	1	0.000	0.000
Error	22	.1252	
Total	45	12.099	

and .995 for the butterfly) and therefore were not recalculated.

Descriptive Analysis

Table 7 lists the means and standard deviations of the vertical jump and reach and each of the four strokes. The means and standard deviations for each test were obtained by subjecting the criterion scores to the SPSS Pearson Corr program. In the vertical jump and reach test, the scores ranged from a high of 32 inches to a low of 16.5 inches. In the crawlstroke, the scores ranged from a high of 12.84 seconds to a low of 10.72 seconds. In the backstroke, the scores ranged from a high of 16.53 seconds to a low of 11.31. In the breaststroke, scores ranged from a high of 19.02 seconds to a low of 12.57 seconds and in the butterfly, the scores ranged from a high of 14.92 seconds to a low of 11.68 seconds. See Appendices D, E, F, G, and H for raw data.

In order to establish a classification system, the criterion scores for the vertical jump and reach were then assigned to one of three categories (Table 8) depending upon the events the subject participated in during the season. Means and standard deviations were then determined for each category. The scores for the sprinters ranged from a high of 32 inches to a low of 26.5 inches. The middle distance swimmers' scores ranged from a high of 27 to a low of 22.5 inches, and the distance swimmers' scores ranged from a high of 25 inches to a low of 16.5 inches.

Pearson Product-Moment Correlations

Pearson product-moment correlations were utilized to determine whether a significant relationship existed between performance in the

Table 7

Means and Standard Deviations of the Vertical Jump and Reach and Sprint Tests

Test	N	M	SD
Vertical Jump	23	24.717 inches	3.492 inches
Crawlstroke	23	11.311 seconds	.604 seconds
Backstroke	23	13.414 seconds	1.183 seconds
Breaststroke	23	15.533 seconds	1.439 seconds
Butterfly	23	12.501 seconds	.730 seconds

Table 8

Descriptive Analysis of Vertical Jump and Reach Scores by Swimmers' Classifications

Sprinters		Middle Distance Swimmers		Distance Swimmers	
ID#	Vertical Jump and Reach Score (in inches)	ID#	Vertical Jump and Reach Score (in inches)	ID#	Vertical Jump and Reach Score (in inches)
3	32	2	23	1	22
4	28.5	7	27	10	22.5
5	29.5	8	25.5	13	21
6	29	11	24.5	14	22
9	28	12	25	15	20.5
17	26.5	16	22.5	18	24.5
		21	24	19	22
		23	27	20	25
				22	16.5
N = 6		N = 8		N = 9	
M = 28.91		M = 24.81		M = 21.77	
SD = 1.828		SD = 1.667		SD = 2.463	
R = 26.5 - 32		R = 22.5 - 27		R = 16.5 - 25	

vertical jump and reach and sprinting ability in the four strokes at the .05 level of significance. Additionally, performance in the four strokes was correlated with the jump height/height ratio to determine if this might be a better indicator of sprint speed than vertical jump and reach height alone. See Appendix I for jump height/height ratios and subjects' heights.

Tables 9 and 10 show the results of the Pearson product-moment correlations between the vertical jump and reach and stroke speeds and the jump height/height ratio and stroke speeds, respectively. According to the test of significance, with 22 degrees of freedom, an _r_ value of ±.404 was needed to indicate a significant correlation at the .05 level of significance. The results of the correlations between the vertical jump and reach and strokes revealed significant negative _r_'s for the crawlstroke, backstroke, breaststroke, and butterfly. The results of the correlations between the jump height/ height ratio and the strokes also revealed significant negative _r_'s for the crawlstroke, backstroke, breaststroke, and butterfly. A correlation betwee the vertical jump height and the jump height/height ratio revealed an _r_ of .976.

On the basis of these analyses, all of the null hypotheses for this study were rejected at the .05 level of significance. This investigation found that there are significant correlations between vertical jump and reach height and sprint speed in crawlstroke, backstroke, breaststroke, and butterfly. This investigation also found that there are significant correlations between a ratio of vertical jump and reach height divided by the person's height and

Table 9

Pearson Product-Moment Correlations between

Vertical Jump and Reach and Sprint Tests

Stroke	N	r
Crawlstroke	23	-.733*
Backstroke	23	-.569*
Breaststroke	23	-.529*
Butterfly	23	-.546*

* $p < .05$

Table 10

Pearson Product-Moment Correlations between

the Jump Height/Height Ratio

and Sprint Tests

Stroke	*N*	*r*
Crawlstroke	23	-.731*
Backstroke	23	-.568*
Breaststroke	23	-.510*
Butterfly	23	-.598*

* $p < .05$

sprint speed in the crawlstroke, backstroke, breaststroke, and butterfly.

Summary

Reliability of the data was determined by the ANOVA intraclass method, subjects by trials design. Non-significant F ratios for trial effect were obtained, showing that the data were trend free. Highly acceptable R's of .990, .994, .830, .931, and .995 for found for the vertical jump height, crawlstroke, backstroke, breaststroke, and butterfly, respectively.

The criterion scores of the crawlstroke, backstroke, breaststroke, and butterfly were compared with the criterion scores of the vertical jump and reach and the jump height/height ratio. Significant correlations were determined between the vertical jump and reach criterion scores and all four strokes. Significant correlations were also determined between the jump height/height ratio and all four strokes. Since all of the r's obtained were significant, all null hypotheses for this investigation were rejected.

Chapter 5

DISCUSSION

This chapter contains a discussion and interpretation of the results. The following topics are discussed: (a) Reliability, (b) Vertical jump and reach, (c) Jump height/height ratio, (d) Swimming sprints, (e) Classification of swimming ability, and (f) Summary.

Reliability

A review of the literature revealed no commonly agreed upon number of trials in administering the vertical jump and reach. Therefore, Counsilman's (1977) suggestion of three attempts was followed. Both Smith (1978) and Ross (1970) indicated that three attempts should be used for the sprint trials also. Since it was the intent of this study to determine the subjects' maximal performances, the best trial for each test was selected as the criterion score. This was also in accord with the suggestions of Counsilman (1977) and Smith (1978). The data for each test were subjected to ANOVA to determine if they were trend free. No significant difference was found between the trials in any of the tests.

Reliability was determined by the ANOVA intraclass correlation method (Baumgartner, 1969). In the vertical jump and reach scores, a reliability coefficient of .446 was obtained. Since this value was much lower than those obtained by other researchers, it was determined to be unacceptable. While the F value was not significant, a trend was suspected due to the large error estimate (MS = 10.075). Therefore, the first trial was dropped and reliability was recalculated with criterion scores chosen from trials two and three. The result was a much more satisfactory reliability estimate of .990. In comparison, Henry (1959) found a reliability coefficient of .880 and Glencross (1960) reported an R of .950 for three trials. Other investigators have turned in higher results. Considine (1970), Herman (1976), and Parcells (1977) all found R's in excess of .980 using six, five, and five trials, respectively.

There are a number of possible reasons for such a low correlation in the first comparison. The first reason could be the low number of trials. Henry (1959) found that his reliability increased to .970 when he increased the number of trials from three to ten. A second reason could be learning. Luthanen and Komi (1978) reported that when subjects were first tested they performed at only 76% of their predicted maximums. With learning and practice, this value rose to 84% in later trials. Parcells (1977) also has suggested that learning can have an effect on the first trial.

In comparison with the vertical jump and reach tests, all the sprint tests produced acceptably high coefficients. The crawlstroke was found to have a coefficient of .994, the backstroke .830, the breaststroke .931, and the butterfly .995. Although there seems to be nothing in the literature with which to compare these, they appear to be well within the acceptable range.

Vertical Jump and Reach

The findings of this investigation statistically support the research hypotheses that there would be significant relationships between performance in the vertical jump and reach and sprint speed in the four competitive strokes. Significant negative correlations of -.733 for the crawlstroke, -.509 for the backstroke, -.529 for the breaststroke, and -.546 for the butterfly were found. The negative values occur because a subject who jumps higher (a greater number of inches) is able to swim faster (fewer seconds).

The coefficients obtained are statistically significant but whether they have a practical significance, especially for predictions, is debatable. Greater absolute values would have been more desirable for a strong relationship to have been identified. A couple of reasons may explain why higher coefficients were not obtained. First, the size of the group tested was small. Second, the range of talent of the group was rather narrow. Both of these problems can have an adverse effect on correlations.

The study's findings are in agreement with many reported in the literature. Counsilman (1977) has also hypothesized that vertical jump and reach performance can be a predictor of swimming ability. His theory is based on the findings of muscle fiber research. Subjects with a greater percentage of FTFs should possess greater ability in power events. Since swimming speed is dependent upon strength and power to a great degree and the vertical jump and reach is a test of power, it is reasonable to assume that it may predict different levels of ability in swimming. A problem with this hypothesis is that the vertical jump and reach is mainly a test of leg power and swimming is an activity which derives most of its speed from the upper body, especially the arms (Holmer, 1974a, 1974b). The literature, however, suggests that it is unlikely that a person would exhibit a great variation in the percentages of muscle fiber types between upper and lower body (Counsilman, 1977; Nygaard & Nielson, 1978). Counsilman further states that it would be better to measure power in the arms but that there is no good inexpensive way to do it at the present time. Therefore, the vertical jump and reach would seem to be the most practical test to use.

Research in muscle fiber typing and identification also supports the findings of this investigation. Thorstensson, Grimby, and Karlsson (1976), Thorstensson (1977), and Tesch and Karlsson (1978) all investigated the relationship between percentage of FTFs in the main extensor muscles of the legs and peak torque developed during isokinetic knee extensions. This is one of the main actions used in performing the vertical jump and reach. Significant correlations ($p < .05$, .05, and .001, respectively) were found in all three studies. Thorstensson, Sjödin, Tesch, and Karlsson (1977) also concluded that muscles with a high percentage of FTFs have a greater potential for more powerful and faster contractions than those with a high percentage of STFs.

Costill et al. (1976) and Nygaard and Nielson (1978) found high percentages of STFs (up to 80%) in world-class distance runners and national and world-class distance swimmers, respectively. Golnick et al. (1972), Prince et al. (1976), and Thorstensson, Larsson, Tesch, and Karlsson (1977) found wide differences between percentages of FTFs and STFs in the muscles of distance competitors and sprint or power competitors. Komi et al. (1977) concluded that a high percentage of FTFs would seem to be a prerequisite for proficiency in power events. All of these findings support the contention that athletes need a high percentage of FTFs to excel in sprint events and a high percentage of STFs to excel in endurance events. If this is so, then athletes who excel in sprints should have more power and, therefore, should perform better in a power test such as the vertical jump and reach.

Jump Height/Height Ratio

The findings of this investigation statistically support the research hypotheses that there would be significant relationships between the jump height/height ratio and performance in the four sprints. The ratio is a slight modification of Sargent's (1921) original efficiency index which was developed with the idea that it could be an easy and practical test of physical ability. The jump height/height ratio was used in this study because it was thought that a person who jumps 50% or 60% of his or her own height very likely possesses a greater amount of sprint or power ability than a person who only jumps 30% to 40%. A second reason is that it would be a more practical type of test to administer, especially in a swimming pool environment, than Sargent's, which involves weight, or Glencross' (1960) vertical power jump. A final reason is that this investigation was concerned with finding a useful and practical test to determine ability differences between swimmers. It was thought that if the vertical jump and reach did not prove to be such a test, this simple alternative which incorporates a slightly different way of estimating power might be.

The high correlation of .976 between the ratio and vertical jump and reach performance indicates that this test is very similar to the vertical jump and reach as a test of power. Since the subjects' heights varied greatly (68 to 77 inches), it would be expected that if a difference in scores attributable to height differences were going to occur it would have. Significant correlations with the sprint events also indicates that it may be used as an adequate replacement for the vertical jump and reach as a predictor of swimming ability. However, it does not really seem to be worth the trouble to calculate, since it slightly increases the explained variance (r^2 increases from .298 to .358) in only one stroke, the butterfly.

Swimming Sprints

Three 25-yard sprint trials with at least five minutes rest between them were administered for each of the four strokes. The number of trials for the distance was used by both Ross (1970) and Smith (1978) in their investigations. Five minutes was judged to be ample time for trained swimmers to fully recover from a 25-yard effort.

Other investigators have attempted to use different numbers of trials and different distances to test swimming sprinting ability. Jensen (1963) used 40- and 100-yard swims on two consecutive days. Gregor (1974) used one trial of the 100-yard crawl while Ainsworth (1970) and Bestor (1972) used one trial of 50-yards for their investigations. Scott (1967) used one trial of both the 25- and 50-yard sprints and Hutinger (1970) used one trial of the 25-, 50-, and 100-yard sprints in their studies.

This study used the 25-yard distance from a pushoff for a number of reasons. First, it was desirable to select a distance long enough for the subject to achieve full speed but short enough that fatigue would not play a significant part. Second, a pushoff type start was used to eliminate differences between subjects in starting reaction time and/or skill in the racing dive. Third, a distance longer than 25-yards would also incorporate reaction time and performance differences for the turn. Further, turns involved the problem of deceleration and acceleration as the swimmer approached and departed from the wall. While it could be argued that testing over a range of distances might produce more accurate results, the inherent problems outlined above make it highly impractical to do so.

Classification of Swimming Ability

In Chapter 4, Table 8 presents the means of the vertical jump and reach performances when subjects were grouped by the actual events in which they swam. The sprint group had the highest mean score, 28.91 inches; the middle distance swimmers group had the second highest, 24.81 inches; while the distance swimmers group had the lowest, 21.77 inches. It is interesting to note that the means of the groups are in the order which both the hypotheses and the literature predicted. The sprint group scores ranged from a low of 26.5 inches to a high of 32 inches, while the middle distance group had a range of 22.5 to 27 inches. The distance group ranged from 16.5 to 25 inches. In comparison, Counsilman (1977) has listed the following ranges: sprinters 24 to 31 inches, middle distance swimmers 18 to 25 inches, and distance swimmers 11 to 22 inches. He attributes the overlapping of groups to the changeability of the FTFs in different types of training. No attempt was made to determine whether there were significant differences between groups because they were not randomly selected and the sample sizes were small and unequal.

The results of this study indicate ranges which are slightly higher than Counsilman's. However, the Cornell team had a lack of quality distance and middle distance swimmers during this season. It is possible that this is a reason for the range being so high. Athletes with higher percentages of FTFs (and higher jump scores) would not perform as well in longer events. Therefore, it would be expected that a team which is weak in distance and middle distance event swimmers would have a slightly higher range of scores. By and large, however, the results of this study are quite close to those reported by Counsilman. Because he has tested a much greater ability range (beginning competitive to world-class) than those used in this study, Counsilman's classification for determining swimming ability on the basis of vertical jump and reach scores is recommended.

Summary

The reliability coefficients for the four swimming tests were all acceptable. No comparisons could be found in the literature. The reliability for the vertical jump and reach (R = .990) was also very acceptable when compared to other studies. Considine (1970), Herman (1976), and Parcells (1977) all reported reliability coefficients in excess of .980. This study, as well as the preceding ones, used the ANOVA correlation method to determine intraclass reliability. The high reliability of the jump and reach was obtained from trials two and three of the test.

Pearson product-moment correlations indicated significant relationships between the vertical jump and reach performance and sprint performance in all four strokes. Significant relationships also were found between the jump height/height ratio and all four strokes. Therefore, the null hypotheses that there would be no significant correlations between vertical jump and reach performance and sprint speed in the crawlstroke, backstroke, breaststroke, or butterfly and that there would be no significant correlations between the jump height/height ratio and sprint speed in the crawlstroke, backstroke, breaststroke, or butterfly were all rejected at the .05 level of significance.

The results of the vertical jump and reach and jump height/height ratio correlations support the theories of Counsilman (1977) in regard to the predictability of swimming ability. They are also in agreement with many other studies (Costill et al., 1976; Golnick et al., 1972; Komi et al., 1977; Prince et al., 1976; Tesch & Karlsson, 1978; Thorstensson, 1977; Thorstensson, Grimby, & Karlsson, 1976; Thorstensson, Larsson, Tesch, & Karlsson, 1977; and Thorstensson, Sjödin, Tesch, & Karlsson, 1977) done in the area of muscle fiber research.

Division of subjects into the swimming categories in which they actually participated revealed ranges of scores for their vertical jump and reach performances which were slightly higher than those reported by Counsilman (1977). Counsilman's divisions were supported, however, because they represented a much larger and more diverse sample than did the subjects in this study.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Swimming coaches are quite often faced with the task of trying to decide whether a swimmer should be trained for sprint, middle distance, or distance events. Thus, they have been searching for easy methods to predict a swimmer's potential. The vertical jump and reach test has been hypothesized to be such a predictor.

The purpose of this study was to determine whether significant relationships exist between vertical jump and reach performance (represented by both the height of the jump and a ratio composed of vertical jump height divided by the subject's height [jump height/height ratio]) and sprint speed in four different swimming strokes. It was hypothesized that both the vertical jump and reach and the jump height/height ratio would correlate significantly with 25-yard sprint performance in the crawlstroke, backstroke, breaststroke, and butterfly.

Twenty-three volunteer male undergraduates on the Cornell University varsity swimming team were given three trials each of the vertical jump and reach, 25-yard crawlstroke, 25-yard backstroke, 25-yard breaststroke, and 25-yard butterfly. The subjects were given 30 seconds rest between the vertical jump and reach trials and at least 5 minutes rest between swimming trials. The vertical jump and reach was measured to the nearest one-half inch and all sprint times were recorded to the nearest one-hundredth of a second.

The criterion score of the vertical jump and reach was determined to be the higher of trials two and three, while the criterion scores for the sprints were determined to be the fastest of the three trials of each sprint. Intraclass reliability was established by R values of .990 for the vertical jump and reach, .994 for the crawlstroke, .830 for the backstroke, .931 for the breaststroke, and .995 for the butterfly, all of which were determined by the ANOVA method. Pearson product-moment correlations revealed significant correlations between the vertical jump and reach and all four strokes (r's of -.733, -.569, -.529, and -.546 for crawlstroke, backstroke, breaststroke, and butterfly, respectively) and the jump height/height ratio (r's of -.731, -.568, -.510, and -.598 for crawlstroke, backstroke, breaststroke, and butterfly, respectively).

Since the results indicated that there were statistically significant relationships between vertical jump and reach performance and sprint speed, Counsilman's classification system for determining swimming performance was recommended.

Conclusions

Within the scope of this investigation, the following conclusions were drawn:

1. Significant negative relationships exist between vertical jump and reach performance and sprint speed in the crawlstroke, backstroke, breaststroke, and butterfly.

2. Significant negative relationships exist between the jump height/height ratio and sprint speed in the crawlstroke, backstroke, breaststroke, and butterfly.

Recommendations

The following are recommendations for further study in this area:

1. It is recommended that the modified vertical power jump be compared to sprinting ability.

2. It is recommended that a study be done which tests specialists in their stroke of specialization rather than non-specialists in all strokes.

3. It is recommended that a larger number of subjects and a wider range of abilities be tested.

4. It is recommended that swimmers of known high ability in sprint, middle distance, or distance events be tested to further clarify the vertical jump height range for each of the three categories.

5. It is recommended that a study be done with female subjects to determine a classification system for them since this study was performed with only male subjects.

Appendix A

INFORMED CONSENT FORM

You are being asked to be a subject in a Master's study being done by Frederick DeBruyn to study the relationship of vertical jump and reach performance to sprinting ability in swimming. As a subject in this study, you will be asked to do the following things:

1. Participate in a vertical jump and reach test which involves doing a standing jump and touching a wall as high as you can. You will be asked to do this three (3) times per testing session.

2. Swim one length (25-yards) sprints in four (4) different strokes, butterfly, backstroke, breaststroke, and freestyle. You will also be asked to do this three (3) times per session with rest in between.

You should understand that you are a volunteer and may withdraw as a subject at any time. All records will be held in strictest confidence. Your signature below certifies that you are 18 years of age or older and that you agree to participate in this study.

____

Appendix B

INSTRUCTIONS FOR THE VERTICAL JUMP AND REACH

These are the instructions for the vertical jump and reach test. You must stand facing the wall with your feet about shoulder width apart. Your toes should be touching the wall and your heels should be flat on the ground. You must reach up with both hands and touch the wall as high up as you can, I will measure your reach. After you have been measured, you may take some practice jumps. When you feel you are ready, chalk your fingers and take your ready position, You may move your arms and bend your knees as much as you want but you may not move your feet until you actually jump. Jump as high as you can and touch the wall at your maximum height. You will be allowed three (3) trials with 30 seconds rest in between to rechalk your fingers and re-position yourself. Each jump should be performed with maximum effort.

Appendix C

INSTRUCTIONS FOR THE 25-YARD SPRINTS

These are the instructions for the 25-yard sprint tests. After you feel that you have had sufficient warm-up, you are to come to me to begin the sprints. You are to start in the water in a position which you feel is comfortable for you as long as you have both of your feet placed on the wall. I will tell you to begin with the command "Go." When you hear the command, you are to push off the wall and swim as fast as you can to the other end of the pool. You will be given 12 trials, three each of butterfly, backstroke, breaststroke, and crawlstroke. You will perform the trials in the following order: three butterfly, three backstroke, three breaststroke, and three crawlstroke. You will be allowed to perform one trial every 5 minutes if you desire, but you will be allowed to take more rest should you feel you require it,

Appendix D

JUMP HEIGHT RAW DATA IN INCHES

Subject #	Trial 1	Trial 2	Trial 3
1	21.5	22*	22
2	23	23*	22.5
3	31	32*	31
4	28	28.5*	28.5
5	28	29.5*	29.5
6	28.5	29*	29
7	26.5	27*	27
8	24.5	25	25.5*
9	27.5	27.5	28*
10	21.5	22.5*	22
11	25	24.5	25*
12	25	24.5*	24
13	21	21*	21
14	22	22*	21.5
15	20.5	20.5*	20
16	21.5	22	22.5*
17	26.5	26	26.5*
18	24	24	24.5*
19	22	22*	21.5
20	24	25*	24.5
21	23	24*	24
22	16	15.5	16.5*
23	27	27*	26.5

* = criterion score (selected to represent the subject's ability in this test)

Appendix E

CRAWLSTROKE RAW DATA IN SECONDS

Subject #	Trial 1	Trial 2	Trial 3
1	11.34	11.29*	11.33
2	11.04	11.04	11.03*
3	10.81*	10.87	10.91
4	11.15	11.10*	11.11
5	10.72*	10.75	10.77
6	10.91	10.94	10.84*
7	10.99	11.01	10.95*
8	11.03*	11.09	11.06
9	11.84	11.70*	11.80
10	12.10*	12.15	12.13
11	11.39	11.32*	11.42
12	11.44	11.52	11.43*
13	11.59	11.53*	11.59
14	12.35*	12.38	12.46
15	11.91*	11.95	11.99
16	12.84	12.82	12.73*
17	10.84	10.91	10.82*
18	11.40	11.32	11.30*
19	11.73*	11.79	11.77
20	11.11	11.16	11.03*
21	10.73	10.84	10.72*
22	12.37	12.46	12.21*
23	10.81*	10.90	10.89

* = criterion score (selected to represent the subject's ability in this test)

Appendix F

BACKSTROKE RAW DATA IN SECONDS

Subject #	Trial 1	Trial 2	Trial 3
1	13.77	13.69*	13.74
2	14.36	14.28	14.18*
3	13.31	13.06*	13.08
4	12.94	12.97	12.86*
5	12.58*	12.63	12.67
6	11.45	11.60	11.31*
7	13.19	13.18*	13.24
8	12.99	13.20	12.97*
9	12.75	12.65	12.61*
10	14.11	14.30	14.06*
11	12.99*	13.21	13.14
12	13.66*	13.66	13.74
13	13.20	13.03*	13.11
14	16.51	16.47*	16.53
15	13.66	13.55*	13.57
16	16.23	16.23	16.19*
17	13.24*	13.41	13.32
18	13.33*	13.33	13.40
19	14.34	14.38	14.26*
20	12.51	12.49	12.43*
21	13.07	13.06*	13.06
22	14.33	14.23*	14.25
23	11.60	11.59*	11.66

* = criterion score (selected to represent the subject's ability in this test)

Appendix G

BREASTSTROKE RAW DATA IN SECONDS

Subject #	Trial 1	Trial 2	Trial 3
1	16.71	16.60*	16.79
2	14.99	15.17	14.93*
3	15.29	15.25*	15.34
4	12.57*	12.71	12.63
5	15.31	15.45	15.26*
6	15.31*	15.47	15.43
7	14.52	14.48	14.30*
8	14.60	14.49*	14.49
9	15.29	15.27	15.26*
10	18.32	18.29	18.16*
11	14.69	14.72	14.66*
12	14.92	14.79*	14.90
13	16.74*	16.83	16.82
14	16.56	16.50	16.47*
15	15.70	15.71	15.65*
16	18.99	19.02	18.91*
17	12.91	12.80*	12.85
18	16.79	16.70	16.69*
19	15.81*	15.84	15.83
20	15.38	15.27	15.22*
21	15.21*	15.26	15.28
22	16.78	16.77	16.69*
23	15.51*	15.53	15.62

* = criterion score (selected to represent the subject's ability in this test)

Appendix H

BUTTERFLY RAW DATA IN SECONDS

Subject #	Trial 1	Trial 2	Trial 3
1	12.95	12.93	12.89*
2	12.13*	12.20	12.19
3	12.21	12.21	12.14*
4	12.06*	12.11	12.20
5	11.84	11.91	11.79*
6	11.95	11.93	11.90*
7	11.74	11.69*	11.80
8	12.78	12.88	12.76*
9	11.68*	11.71	11.77
10	12.40*	12.40	12.46
11	12.17	12.25	12.15*
12	13.41	13.32	13.25*
13	12.88*	12.92	12.97
14	13.36	13.33	13.21*
15	12.94	12.91	12.80*
16	14.92	14.92	14.91*
17	12.72	12.70	12.67*
18	12.85	12.87	12.71*
19	12.99	13.02	12.87*
20	12.21	12.11*	12.14
21	11.92	11.87*	11.93
22	12.99	13.11	12.96*
23	11.74	11.76	11.70*

* = criterion score (selected to represent the subject's ability in this test)

Appendix I

SUBJECTS' HEIGHTS IN INCHES AND JUMP HEIGHT/HEIGHT RATIOS

Subject #	Height	Jump Height/ Height Ratio
1	74	.297
2	70	.329
3	68	.471
4	68	.419
5	69	.428
6	73	.397
7	68	.397
8	73	.349
9	68	.412
10	67	.336
11	75	.327
12	71	.352
13	72	.292
14	75	.293
15	74	.277
16	75	.300
17	72	.368
18	71	.345
19	77	.286
20	72	.347
21	72	.333
22	69	.239
23	71	.380

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