A CINEMATOGRAPHICAL ANALYSIS OF TEN BREASTSTROKE SWIMMERS, INCLUDING CERTAIN STRENGTH AND ANTHROPOMETRIC MEASURES

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ABSTRACT

A CINEMATOGRAPHICAL ANALYSIS OF TEN BREASTSTROKE SWIMMERS, INCLUDING CERTAIN STRENGTH AND ANTHROPOMETRIC MEASURES

by Ann W. Chadwick

Ten breaststroke swimmers ranging in ability from mediocre to Olympic medal winners were filmed under water. Each subject swam past, toward, and away from the camera for different views of his stroke. Cyclic velocity, stroke co-ordination and body position measures during each phase of his stroke were determined. Selected strength, flexibility and anthropometric measures were also recorded.

Most of the 42 measures comprising each swimmer's variables were put into the Data Process Computer at Michigan State University a total of three times, in different combinations. After the importance of each variable to the criterion variables was statistically computed, the following conclusions were drawn: Speed of breaststroke is increased when (a) the swimmer's cyclic velocity remains relatively constant, (b) when breathing occurs relatively late in the arm pull, and (c) when the swimmer's arm pull is efficient and powerful enough to result in a high arm velocity. The swimmer's speed is decreased (a) when his glide is so long that his velocity decreases significantly; (b) when the hip flexion angle at the end of his leg recovery approaches 90°, thus creating increased drag;

and (c) when a number of other measured factors contribute to poor body streamlining. A number of other measures were all found essential to an outstanding swimmer, such as (a) good ankle flexion, (b) good foot outward rotation flexibility, (c) high leg adduction strength, (d) high knee extension strength, (e) high latissimus strength, and (f) high arm pronation strength.

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By

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CHAPTER I

INTRODUCTORY MATERIAL

Although breaststroke is one of the oldest methods of swimming, it is still the slowest of all competitive strokes because it has inherent mechanical disadvantages. Arm recovery under the water is one, and recovering legs together, also under the water, is another.

Within the framework of rules set by F.I.N.A. and other governing bodies for swimmers, there are many different styles of swimming breaststroke which meet with success. The types of strokes found in one race are often greatly different in form, yet each swimmer in his own way seems to produce fast times.

The United States swimmers as a whole have been doing well in the Olympic Games recently. In the freestyle, butterfly and backstroke events, U.S. swimmers usually place quite high, and many times first. Breaststroke races are an exception, however. They are usually won by the Russians or Europeans; third place is the best the U.S.A. Olympic swimmers have been able to do recently. In view of this fact, it seems necessary to study the breaststroke further.

Purposes

This study was undertaken for the purpose of doing a mechanical analysis of ten breaststroke swimmers ranging in ability from mediocre to Olympic medal winners. From the conscientious study of their strokes, several categories of facts should be learned.

First, by comparing outstanding swimmers with mediocre swimmers, general differences in areas of velocity, stroke co-ordination, anthropometric measures, flexibility and strength should develop.

Second, the question, "Do swimmers with similar anthropometric measures tend to swim the same way?" may be answered. If so, this study may be able to suggest a "best" style of breaststroke for people with a given body type.

A third problem is to determine if significant differences in breaststroke swimming styles exist between men and women. Because of sex-related anthropometric differences, if there are significant stroke differences too, this study may be able to recommend a type of stroke best suited to each sex.

The last problem is on the primary cause of breaststroke inefficiency: leg recovery. What methods do outstanding swimmers employ to minimize water resistance at that point? What differences in stroke co-ordination enable them to keep their stroke velocity higher at the end of their leg recovery? Most breaststroke swimmers have a momentum lag and a marked cyclic velocity drop between the end of their arm stroke and the beginning of their leg kick; better swimmers do not. This study will attempt to determine if this is due to anthropometric advantages, better streamlining ability, or better stroke co-ordination.

This study will not concern itself with a comparision of the old wedge-type kick and the newer whip kick. Cake (5) and Counsilman (7) as well as the current good breaststroke swimmers have all shown that the whipping motion is far superior to the squeeze pattern of the wedge kick.

Definitions Used in This Study

Wedge Kick.--This is the older type of breaststroke kick commonly used prior to 1940. During leg recovery, the knees are spread wide, the heels are together and the feet are drawn up toward the crotch. The power phase begins as the legs are flung out to the side and rear, and into a wedge shape; it ends as the legs are squeezed together forcibly. There are three definite counts or stages in this kick: (a) recovery, (b) kicking out, and (c) squeezing the legs together.

Whip Kick.--This kick is used by most swimmers who do the "Quick" or "Jump" stroke. Recovery begins as the heels are brought up towards the buttocks and the knees are flexed downward. Both the heels and knees are kept within the shoulder width. The power phase begins after the feet are outwardly rotated and the ankles are flexed. The feet and lower legs immediately thrust back and down against the water. The heels kick to a point slightly outside the shoulder width, but the knees remain inside. The power phase ends as the legs are brought together at the same time they finish whipping back and down; this whipping motion is one smooth action from beginning to end. Primary thrust comes from pushing the legs and feet back and down against the water, not squeezing the legs together. This whole kick cycle can be completed in two counts: (2) recovery, and (b) thrust.

Modified Whip Kick or Standard Breaststroke Kick.--This kick is currently used by most European and American breaststroke swimmers. It is essentially the same as the Whip Kick except that the leg kick is generally wider. Leg recovery begins as the heels are brought up towards the buttocks and the knees are flexed downward and outward. The heels are within the shoulder width, but the knees may be a little wider. The power phase begins after the feet are quickly rotated outward the the ankles are flexed. The feet and lower legs immediately thrust back, out and down against the water, in a smooth sustained action from begining to end. The knees and feet go wider than in the Whip Kick. They do not stop at the side position as in the Wedge Kick. The knees are kept rotated slightly inward and they squeeze together while the feet swing to their widest position. The power phases ends as the legs finish pushing downward and are squeezed together. The power of this kick comes from two sources: one is the pressure of the legs and feet kicking back and down; kicking the feet outward as the legs are squeezed together is the other. The entire whipping motion is a very smooth and co-ordinated action. This kick can also be completed in two counts: (a) recovery and (b) thrust.

Quick or Jump Stroke.--This is the newest method of breaststroke swimming, pioneered primarily in the United States. It is basically the Standard or Slow breaststroke that has been modified and quickened. Its primary characteristic is its fast stroke cycle time. The swimmer's shoulders are usually higher out of the water than in the Standard stroke, and he may appear to jump along the water surface. The arm pull pattern is usually narrower and deeper than in the Standard stroke. The arms may push back until they are directly perpendicular to the water surface. The arms recover quickly; they do not stretch for a long glide, but begin pushing back immediately. The leg kick used is the Whip or a fast Modified Whip. There is very little pause at the end of the kick before the leg recovery begins again. Breathing comes very late in the arm-pull pattern and is fast. The stroke cycle time may be only one-half that of the Standard stroke. More emphasis is placed on the arm pull than in the Slow stroke, indicating a necessity for greater arm strength. This stroke is very powerful, explosive and fast.

Standard or Slow Stroke.--This is the common breaststroke currently used by most European and American breaststroke swimmers. It is sometimes called the Glide stroke. It is generally characterized by a wider arm and leg pattern, longer glide and slower stroke cycle time than the Quick stroke. There is also a greater emphasis on the kick over the arm pull. The arm pull begins as the hands and forearms push back and out. The arms follow, pushing back to a point about six to eight inches in front of the shoulders and under the body. The pull is usually wider and shorter than in the Quick stroke. As the arms finish pushing back and begin circling under the chin for recovery, the head is lifted for a breath, and the legs finish their recovery. After outwardly rotating the feet and flexing the ankles, the legs begin their thrust. The kick pattern is that defined in the Modified Whip kick. As the leg thrust begins, the arms shoot out to a stretched position. When the legs finish kicking and squeeze together, the body is streamlined for the glide, which is longer than in the Quick stroke. The body remains almost level with the water surface, and the shoulders do not rise as high as in the Quick stroke. Basically, this is a smooth, powerful, efficient stroke and beautiful to watch.

Other strokes.--These are usually modifications of either the Standard or Slow stroke, or else the Quick stroke. Each breaststroke swimmer seems to choose which components of the two basic strokes he likes best and combines them together in his personal way. This is the reason for the great difference in breaststroke swimming styles today.

Subjects

Name	Club	Best Time	
		100 Yds.	200 Yds.
Ann Bancroft	Foothills Acquatic, California	1:09.5	2:30.4
Johanna Cooke	Motor City, Michigan	1:13.2	2:39.8
Cynthia Goyette	Motor City, Michigan	1:09.6	2:29.1
Patricia Schmidt	Cleveland Swim, Ohio	1:21.0	2:49.8
Lee P. Driver	Michigan State University	1:02.3	2:18.2
Peter Fetters	East Lansing High School, Michigan	1:12.8	2:30.1
Mark Hunt	Michigan State University	1:03.6	2:19.8
Chester Jastremski	University of Indiana	:58.5	2:09.0
Dennis Manrique	Michigan State University	1:07.2	2:28.6
Jack Marsh	Michigan State University	1:05.0	2:25.0

These swimmers' times were taken before the fall of 1964, and consequently some have changed considerably since then.

Limitations

(a) Ann Bancroft's and Chet Jastremski's strength and some anthropometric measures had to be approximated, due to the impossibility of obtaining these at the time they were filmed and under the same situation as the other subjects.

(b) Strength measures were taken in a laboratory situation, but positions were as close as possible to the actual swimming stroke.

(c) Filming swimmers and projecting them on a screen to plot their velocity is a complicated process in which errors could occur. Care was taken to prevent these: The camera spring was wound tight, the projector distance from the screen was marked, and fixed points on each swimmer were carefully plotted. If errors did occur, they will be reflected in the data.

(d) Since there were only 10 subjects and some 42 variables in the problem, it is difficult to speak with real statistical significance; however, the data shows statistical trends.

CHAPTER II

REVIEW OF RELATED LITERATURE

Brief History of Breaststroke

> When Captain Matthew Webb, the celebrated long-distance English swimmer swam the English Channel from Dover to Calais in 21 hours and 45 minutes on August 24 and 25, 1875, he used the breaststroke. However by August 6, 1926, Gertrude Ederle, an American woman, crossed the Channel in 14 hours and 31 minutes using primarily crawl stroke (17).

The average swimmer from 1850 to 1900 used mostly breaststroke or sidestroke. A wide wedge-type breaststroke kick was the usual kick done for most types of swimming at that time, including the crawl (17).

Breaststroke has gone through many changes. First it was done with the head held high out of the water; later the swimmers put the head into the water and lifted it out during breathing only. At first, the wide wedge kick and wide arm pull were used; later the entire stroke was modified.

In 1934, Armbruster (3) began experimentation on a new type of stroke which was to significantly change the history of breaststroke for about 20 years. The arm pull pattern his swimmer used was similar to the front crawl, except that the arms worked simultaneously; and they recovered over the surface of the water instead of under. The leg kick he tried was named the Dolphin kick, and it employed up and down movements of the legs and feet, which were held together. This new stroke was called the Butterfly. Although the Butterfly was considerably faster than the orthodox breaststroke, due to the up and down movements of the legs, the dolphin kick was ruled illegal. Swimmers using the Butterfly arm stroke therefore began using a short, narrow, quick breaststroke kick; which developed into our present day Whip kick.

By 1954, the F.I.N.A. separated the new Butterfly stroke with the Dolphin kick, from the Orthodox Breaststroke, and made each stroke an individual event within a framework of its own rules. In January 1958, the National AAU adopted the F.I.N.A. International rules for all breaststroke swimming in the United States (13). These rules spelled out the prescribed form for the breaststroke. They eliminated arm recovery over the surface of the water, the Dolphin kick, and specified that a portion of the swimmer's head must remain above the surface of the water during the race except for one stroke underwater on his start and each turn (13). These rules haven't changed appreciably since that time.

Related Studies

The swimming literature is beginning to show many very good scientific studies on stroke analysis, training, starts, turns and diet; (1, 7, 8, 9, 10, 11, 12, 15, 20, 21, 23, 14, 28). However, there are still some questions which need study.

Counsilman did a study (8) on the cyclic velocity fluctuations of two types of crawl stroke. He used an apparatus designed to tow or release a swimmer at several controlled velocities. He recorded velocities and fluctuations in the propulsive force of three expert swimmers.

One subject was towed in different positions to study the degree of water resistance accompanying each position. Then he tested two strokes, the glide stroke and the continuous stroke, at two tempos: sprint, and distance. The amount of fluctuation in force was measured. This force fluctuation measure is similar to the velocity fluctuations that are measured by a cinematographical analysis.

Counsilman concluded that resistance created in the several drag positions was from least to greatest in order as follows: Prone position, side position, being rolled by external force, and a self-rolling position. He found that a bow wave appeared between between a velocity of 6.55 and 7.03 feet per second, greatly increasing water resistance. This was not affected by the position in which the swimmer was being dragged. He also found the continuous stroke created more effective-propulsive force than did the glide stroke for the same tempo and velocity. The continuous stroke was also the fastest stroke over a measured 10 yards. He found that the glide stroke created more fluctuations in force than did the continuous stroke at the same velocity and stroke tempo (8).

DeVries (10) did a cinematographical analysis of the Butterfly with the dolphin kick, filming two subjects. One subject was a national champion and the other a good collegiate butterfly swimmer. It was interesting to see the velocity fluctuations he found in butterfly from the simultaneous arm recovery. The national champion had a mechanically superior stroke, showing less velocity fluctuation, and the ability to travel further in each stroke.

Plummer (22) did a study on cyclic velocity variations of the breast and butterfly strokes. Through use of the Natograph, he was able to make accurate velocity calculations on six subjects. He then plotted their cyclic velocity variations while swimming the following: Fast butterfly stroke, fast breaststroke, fast underwater breaststroke, arms alone on butterfly, arms alone on breaststroke, and legs alone on the frog kick.

This study was done in 1938, and the stroke description of the current breaststroke of that time is as follows:

> The arms are brought back quickly sideways to a point about in line with the shoulders. The legs are still together. When the arms are circling to the starting position ready to shoot forward, the legs are brought up in position to kick backward. The arms then thrust forward as the legs shoot back and out. Next, the arms remain stationary and extended at full length with the palms together while the legs are snapped together. The bringing together of the legs is done quickly and smoothly, and immediately after the arm movement forward and the leg movement backward. Then comes the glide of from six to seven feet, arms and legs extended out full length (22).

The frog kick used in Plummer's study was a combination of what we would term a "wide wedge kick" and a "wide whip kick" with the knees apart much more than the newer, narrower whip kick used today.

> The legs separate while recovering, then they extend together in the rear, the legs are spread at once into a wide straddle position with a bending of the knees sideways. Upon reading the full spread position, the legs are given a vigorous slap inward. It is really one motion . . . reaching the position and slapping back . . . resembling the flapping of two fish's tails together.

Plummer concluded that the long glide, commonly done then, should be greatly shortened, and that the arm pull should begin just as soon as the leg kick had been completed. He recommended a kick closer to our whip kick of today. He said the narrow kick would be an improvement since water resistance is lessened (22).

Manwell and Clement (19) did the only recent cinematographical study on the style of breaststroke which this study will include. It was a kinesiology project at Michigan State University. They did a cinematographical analysis of Manwell's breaststroke to help improve his performance on the Michigan State swimming team. They used a camera speed of 64 frames per second, a ball drop for determining the time value of each frame, and a yard stick for linear distance. By using a motion analyzer, they were able to compute and chart Manwell's moving velocity, thus giving him an idea of what to improve on his stroke.

Water Resistance

Water resistance is an extremely important factor for a mechanical analysis of the breaststroke because of the acceleration-deceleration problem. Most all breaststroke swimmers have a marked cyclic velocity variance; some more extreme than others. Therefore, the three items this study will consider when determining the effect of water resistance on breaststroke are: (a) Skin Friction, (b) Eddy Resistance, and (c) Wavemaking Resistance.

Skin Friction

This is based on the surface area of the swimmer, together with the speed at which he moves through the water (24).

According to Whitehead (26) if the body is streamlined while moving, a certain amount of water will stick to and move along with the swimmer. The layer of water adjacent to that will flow by, following the streamlined form of the body. Next to it will be more layers of water, each steadily decreasing in moving velocity until the layer which remains at rest. This is the normal pattern of laminar flow of a liquid around a streamlined object.

Karpovich (16) states that the shape of the object is more important than the surface area, although there is a general relationship between size and resistance. The skin friction is increased as the swimmer's speed increases, and the water resistance is greater when accelerating to reach a certain speed than it is to maintain that speed.

Bunn (4) states that very heavy gluti muscles cause the buttock to protrude and will tend to create a greater water resistance. Hip girth, thus, may be an important factor in proper streamlining of the body for good laminar flow.

Skin friction, thus, causes a large degree of wasted energy in breaststroke with its major cyclic velocity fluctuations. This is especially true for the less-skilled swimmer who has the greater velocity fluctuations.

Eddy Resistance

This is caused from a non-streamlined body moving through the water (like the leg recovery in breaststroke). This causes a disruption of the smooth laminar flow, separating the layers. It results in dead water, turbulence, eddies and suctions or drag. This eddy resistance increases in direct proportion to the angle of irregular streamlining. Therefore in breaststroke, the further the legs are drawn out of line during leg recovery, the greater the increase in resistance. Most of this resistance comes from between the hip and the knee, so the greater the hip flexion during recovery, the greater will be the resistance (1). Efficient propulsion in swimming is dependent then upon minimizing resistance and applying force (25).

Wave-Making Resistance

This is caused from motion taking place at the surface of the water. The forward acceleration of the swimmer causes a change in the normal distribution of hydrostatic pressure. As a result, changes of elevation occur, constituting a wave (26). Although most wave-making resistance studies have been concentrated on ships (21, 6), Alley in 1952 (2) noted a bow wave when a swimmer's velocity reached 5 feet per second. At 6.4 feet per second, the wave had increased to the extent that it very materially increased the drag. This bow wave, therefore, is an important factor in the limitation of speed in swimming. Thus a swimmer who has a strong powerful stroke, but marked velocity variance will be expending much of his energy just changing velocity. This energy drain increases markedly as he passes the 6.4 feet per second mark.

With this information on water resistance as a background, it is clear that cyclic velocity fluctuations in breaststroke greatly increase its inefficiency. It would seem reasonable that a method to decrease these fluctuations should be found.

CHAPTER III

METHOD FOR OBTAINING DATA

Photography

The subjects were all filmed through an underwater window. Bancroft, Cooke, and Goyette were photographed at the University of Pittsburgh during the 1964 Women's AAU Indoor Nationals. Jastremski was filmed by his coach, Dr. Counsilman, at the University of Indiana, Bloomington. All other subjects, including Cooke and Goyette for the second time, were filmed at Michigan State University, East Lansing in the Men's Intermural pool.

Each subject swam past the camera using his fastest breaststroke at least twice. Each had from 25 to 30 feet to gain maximum speed before coming within camera range. After the profile view was complete, each subject swam directly toward the camera from the opposite pool wall for a front view of the arm pull angles. Next, each swam away from the camera for a back view of the whip kick pattern. The Bell and Howell camera used in this study was held stationary; speed was set at 48 frames per second during velocity swims. Jastremski was filmed with a moving camera, so his progress was plotted in relationship to a grid on the pool wall behind him.

Standards of Computation

Velocity was computed from standards obtained while filming a falling object. A basic gravity free-fall formula, $S = 1/2gt^2$, was used. Since the films for this study were taken at three different locations, the common number for gravity (32 ft.) was used in the equation. The distance of the ball drop was 8-1/2 feet, gravity was 32 feet, and the time for the ball to drop 8-1/2 feet was .7281 seconds. During this time, 33 frames passed through the camera. This showed that the camera was 9.4% slower than 48 frames per second, because 34.94 frames should have passed during this time for the camera speed to be exactly correct at 48 frames per second. However, 48 frames per second was the time factor by which all velocity measures were computed. All subjects were uniform, and their basic velocity was adjusted accordingly.

The time for one frame at a camera speed of 48 frames per second is .02083. By using a motion analizer, the swimmers' motion was stopped every 4th frame and plotted. Time between plotted points, therefore, is 4 X .02083, or .08333 seconds.

Linear distance was obtained by filming a yardstick. This was placed the same distance from the camera that the swimmers passed for their velocity determinants. By knowing the exact height of the subjects, this could also be double-checked. The distance between each plotted point was very carefully measured, and each subject's velocity was then computed from the basic velocity formula: v = d/t. By computing the swimmer's velocity for each plotted point, an accurate account of his inner-stroke velocity fluctuations could be measured. By examining the body position at each plotted point, and measuring the angles with a protractor, a fairly complete mechanical analysis of each swimmer's stroke was possible.

Explanation of Measures

In this study there are seven basic categories of measures for each subject, and a total of 42 separate items. They were all necessary for a thorough analysis of the swimmer and his type of stroke. The seven basic categories are as follows: velocity measures, body position at end of leg recovery measures, anthropometric measures, flexibility measures of feet and legs, inner stroke timing and co-ordination measures, strength measures, and fastest breaststroke swimming times.

All of these basic categories will be briefly explained here; for a more complete explanation of each one of the 42 separate variables, how it was measured and computed, see Appendix A.

Velocity.--These measures are: high velocity, low velocity, average velocity, leg velocity, arm pull velocity. difference between low and high, and velocity variance. They were obtained basically by computing each swimmer's velocity at the plotted point taken every 4th frame through a series of his stroke cycles. By comparing velocity at a given plotted point with the swimmer's body position, these velocity measures could be figured. For a uniform point to begin velocity figures for all subjects, the start of the stroke was determined as follows: Beginning of leg thrust followed by the glide, arm pull, breath, and leg recovery.

Velocity variance deserves special mention here because it is a measure of variance from the swimmer's average velocity, and the usual formula for standard deviation was used to compute this score.

Stroke Angles at End of Leg Recovery.--These measures were taken of arm position, body angle, back extension, and hip and knee flexion. In terms of exact angles, they represent the measured position of the swimmer's body at the end of his leg recovery. They were measured with a protractor from lines drawn through the swimmer's elbow, shoulder, hip knee and heel on his projected image on the screen at the exact time that he completed his leg recovery. These measures show distinct differences among the subjects, indicating which swimmers had the best streamlining and the least water resistance.

Anthropometric Measures.--These measures were taken on each subject: weight, height, ponderal index, arm span, shoulder width, hip width, waist width and circumference, lower leg length, upper leg length, total leg length, and foot area. These gave a good indication of body type, and especially limb dimensions which might be important to a mechanical analysis of the breaststroke. These figures were used to compare stroke type with body type for each swimmer.

Flexibility Measures.--These were foot outward rotation, and ankle flexion. They determine the swimmer's flexibility in a key kick position--the beginning of leg thrust backward. The measures were taken with a large protractor and the joint flexion angle was recorded.

Stroke Timing.--These measures are all in terms of per cent or total time and are as follows: amount of stroke complete at breath, amount of stroke the head is above water for the breath, amount of stroke there is no power during the negative leg recovery, amount of glide, and total stroke cycle time. These measures give a reasonably complete idea of the inner-stroke co-ordination pattern of each swimmer. Total frames in which the subject was performing the measured item were counted, and this per cent of the whole stroke cycle was then computed. For a uniform measure, the point at which the glide was completed and the first downward movement of the arm stroke began, was considered the start of the swimmer's stroke. Next followed the breath, the leg and arm recovery, the leg kick and the glide. Over all, the percentages varied greatly among these ten breaststroke swimmers, which indicated their extremely different stroke styles and co-ordination patterns.

Strength Measures.--These were based on the following: latissimus strength, forearm pronator strength, knee extension strength, and leg adduction strength. These measures were computed to pounds of strength per pound of body weight. From these strength measures, another variable was computed: average strength. Many other strength measures could have been taken, but these were arbitrarily judged most essential. All strength measures were taken at the Michigan State University Human Energy Research Laboratory by using a tensionometer and steel cable. The best of two tries was recorded, and all measures were taken in prescribed form at right angles to the lever being tested.

Fastest Swimming Times.--These were the swimmers' best meet times on 100 and 200 yards during or before 1964. An arbitrary rank of success, based on these times was also used in this study as an evaluation measure.

Explanation of Computer Use

When all of the measures had been calculated, there were a total of 42 variables on each of the 10 subjects. To simplify the correlation problem, the Michigan State University 3600 Data Process Computer was used for analysis. The computer program selected was the basic core program with correlation or regression analysis.

In order to obtain as much information as possible from the data, the 42 variables were put through the computer once for each of the following classifications: all 10 subjects, 6 men, 4 women, 5 Quick stroke, and 5 Standard stroke subjects. Special information with reference to each of these groups is mentioned in the data. Three of the variables were considered as dependent variables and used as comparison standards for the other measures. They were: Average Velocity, Best 100 Yd. Breaststroke Time, and Success Rank. From these five runs through the computer, a table of correlations with the dependent variables was obtained. This table shows which of the 39 independent variables had significant correlation with the 3 dependent variables for each of the 5 subject classes.

For the next part of the study, some of these 42 variables were combined with others in a formula. These combinations represented an entire classification of data, or a specific part. For example, four measures of velocity were combined in a formula to represent "magnitude of velocity." Another two measures in a different formula represented "uniformity of velocity."

Nine combined sets of variables and two dependent variables were put through the computer in this second part of the study. The two dependent variables used as comparison criteria were Average Velocity and Success Rank. One run through the computer was made for each of the following groups of subjects: All 10, 6 men, 4 women, 5 quick stroke, and 5 standard stroke. After compiling a chart showing correlations of these 9 combined measures with the two dependent variables, the data was ready for its final run through the computer.

Using the two previous correlation charts as guides, those variables which had consistent high correlation with the independent variables were kept. Some of these, however, were eliminated if they also had high inter-correlations with other dependent variables. The remaining variables were then combined by formulas into 14 measures, plus the two dependent variables, average velocity and success rank within sex. The total of these 16 combined variables represented all significant measures on the subjects and their strokes which were taken in this study. From these final 16 variables, a chart of simple correlation was obtained using all 10 subjects.

For the Final Regression Solution, the 14 combined measures and 2 dependent variables were put into the computer. Through the use of a number of "P" cards and regrouping the data several different times (6 independent and 2 dependent variables per group), the computer was able to give a final solution. This final table of computer data includes the Multiple Regression Coefficients, Standard Error or Estimate, Beta Weights, and other statistics. It represents the statistical significance of this study in correlating the 14 combined measures with Average Velocity and Success Rank within sex for all 10 subjects.

CHAPTER IV

RESULTS OF DATA

Observations on Subject's Scores

After figuring the 42 variables on each of the 10 subjects, it is noted that there are several interesting facts to discuss.

Velocity Variables

In examining these, it is noted that Goyette has the highest net Leg Velocity for women (4.943), and Marsh has the highest for men (5.460). Both swimmers have excellent modified whip kicks. Jastremski, had the lowest Leg Kick velocity (2.746), yet the highest Average Velocity of all 10 swimmers (4.973). He has an extremely fast stroke cycle and uses a quick whip kick.

Bancroft has the highest arm velocity for women (1.80). She does the quick stroke and depends on her powerful arm pull much more than the other women. Manrique is high for men (2.97), and Jastremski is second (2.17). Both these men use the quick stroke and have powerful arm pulls (see Figure 1a and 1b).

During the last part of their leg recovery, all the subjects hit their lowest velocity. It would seem reasonable

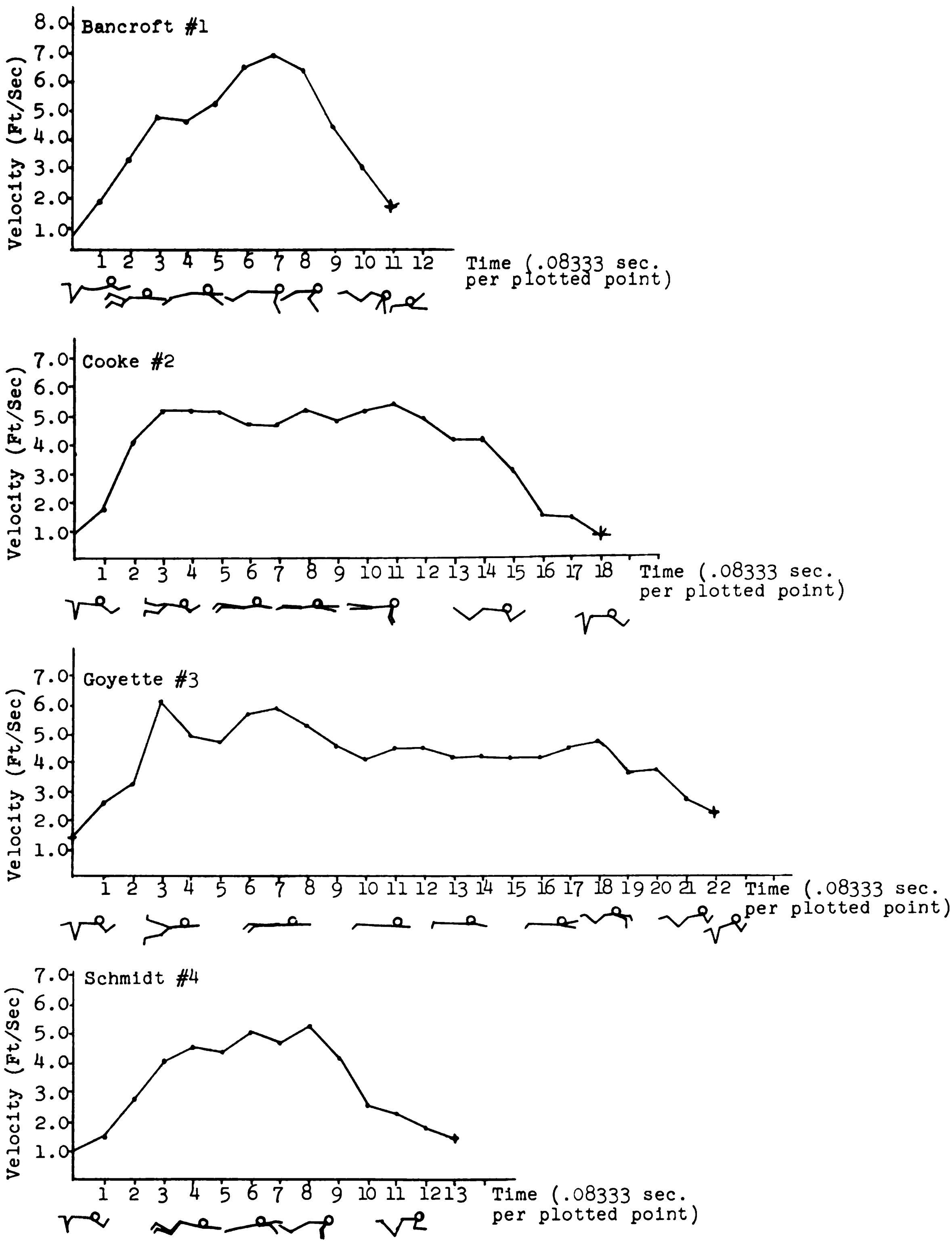


Figure 1a.--Stroke Velocity Fluctuations--Women.

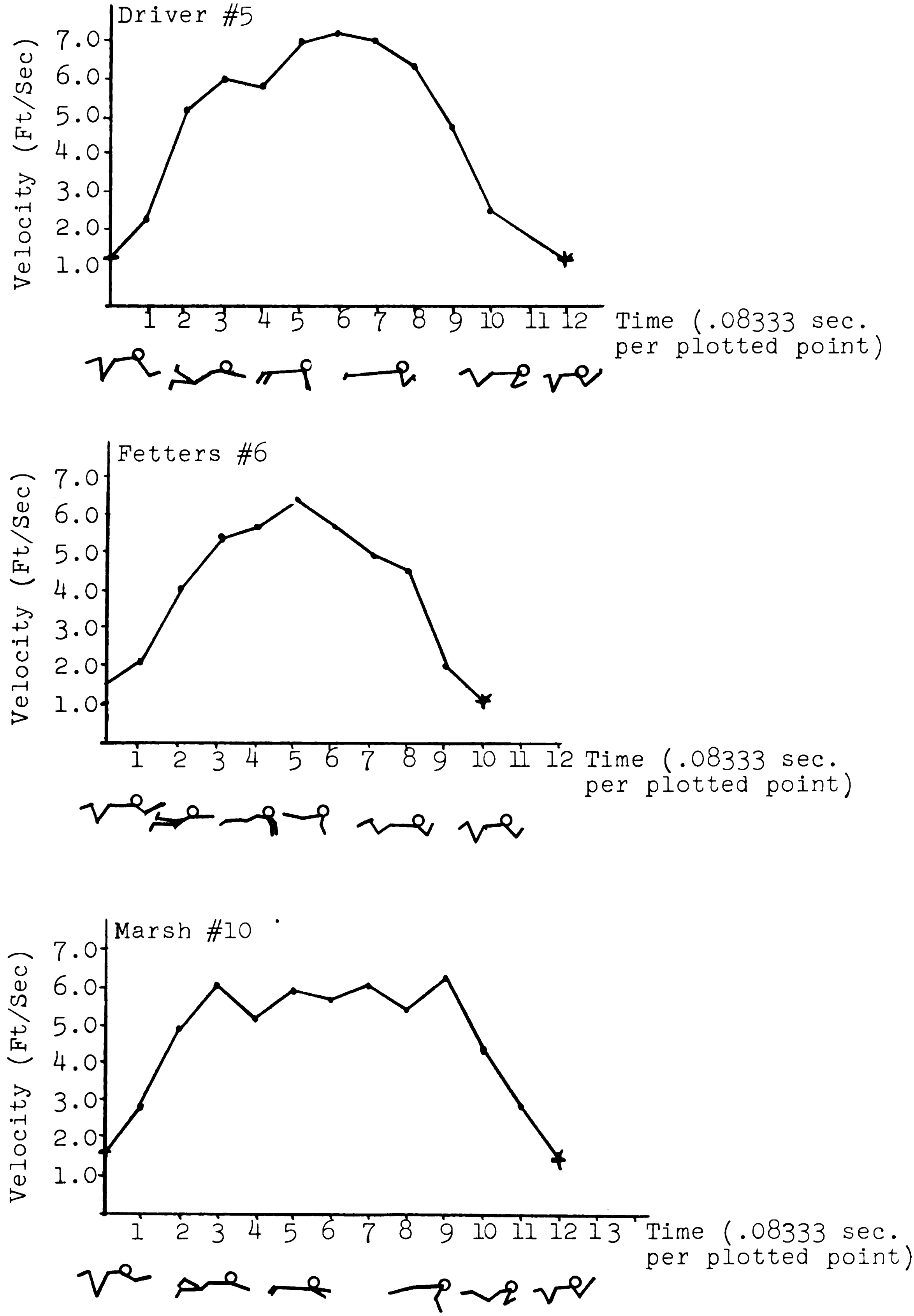
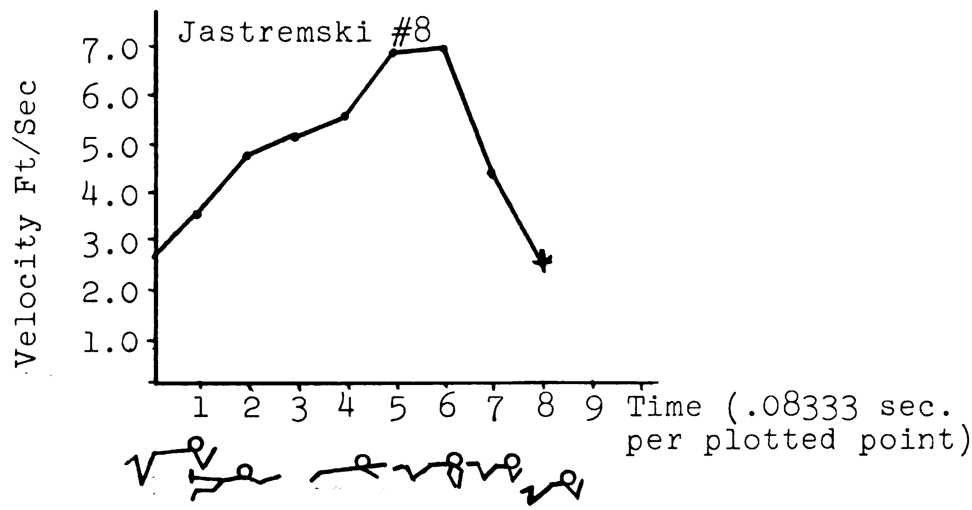
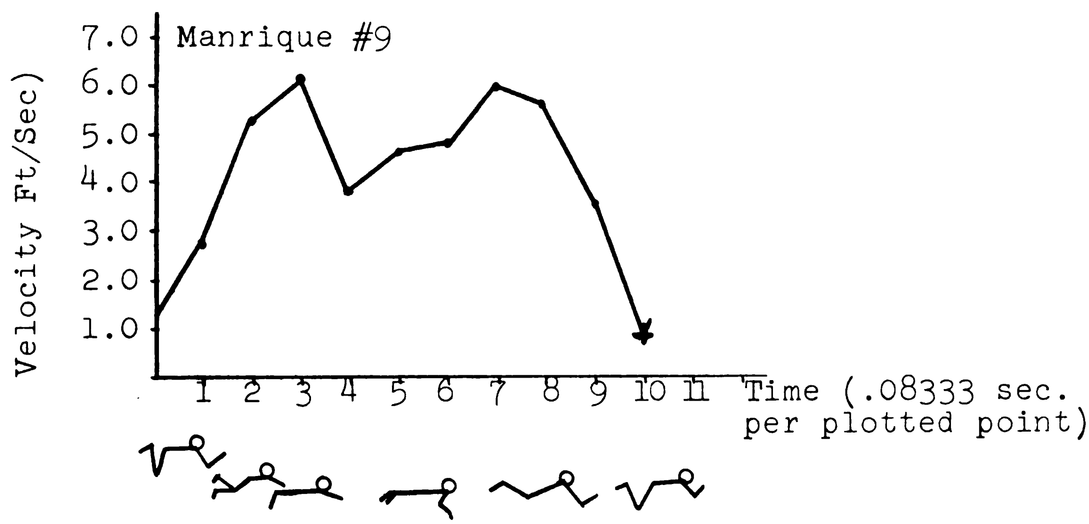


Figure 1b.--Stroke Velocity Fluctuations--Men.





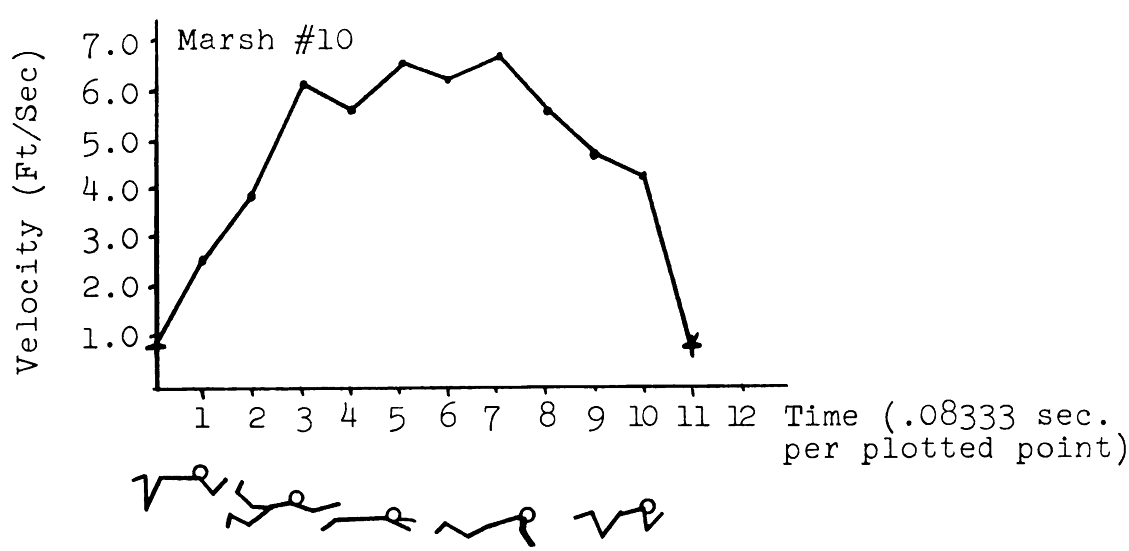
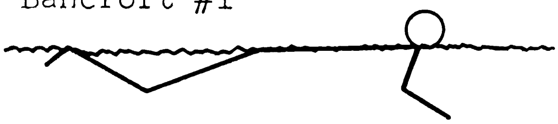


Figure 1b--<u>Continued</u>.

that the higher this velocity remains, the less water resistance must be overcome as the swimmer begins his leg kick and accelerates. Goyette had the highest measure of low velocity for women (1.593), and Jastremski was the highest for men (2.480). Several interesting factors influence this, even though these two subjects use totally different breaststroke styles. Both subjects begin their leg recovery rather early in the stroke cycle, as noted in Figure 2 "Body Position at Beginning of Leg Kick." Neither of these subjects bends at the hips until the very end of their leg recovery, as noted in Figure 3 "End Leg Recovery Position." This apparently causes less water resistance during the early part of leg recovery, enabling the arm pull to continue normally, and the velocity to remain constant. Not until the latter part of their leg recovery do these subjects loose velocity fast. Because they already have finished part of their leg recovery before this point, they are able to begin their leg thrust sooner, and their velocity never drops as low as the other subjects' velocity.

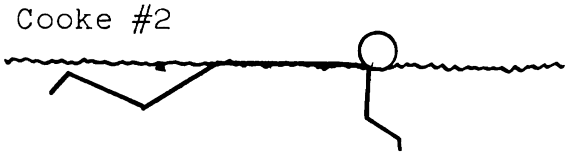
Variable #6, Velocity Variance, is actually a measure of standard deviation or velocity fluctuations from average velocity. Theoretically, a swimmer who is able to keep his cyclic Velocity Variance at a minimum should have a mechanically more efficient stroke. Goyette (1.201), and Jastremski (1.585), again come out ahead of their sex, maintaining the lowest ratio of velocity fluctuations.

Bancroft #1



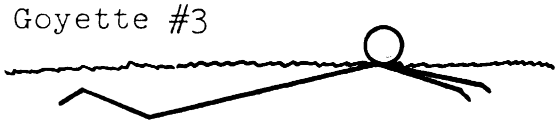
Leg recovery begins as arms recover.

Cooke #2



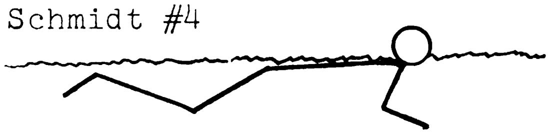
Leg recovery begins at end of arm push

Goyette #3



Leg recovery begins as arm pull begins. No bend at hips until arms complete push and begin circling for recovery.

Schmidt #4

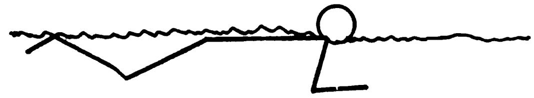


Leg recovery begins as arm recovery begins.

Driver #5

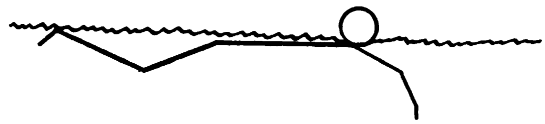
Leg recovery begins after arm recovery begins.

Fetters #6



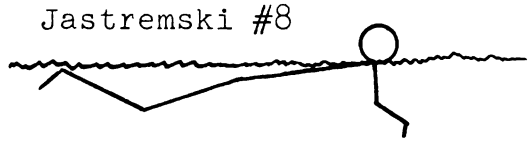
Leg recovery begins after arms begin recovery.

Hunt #7



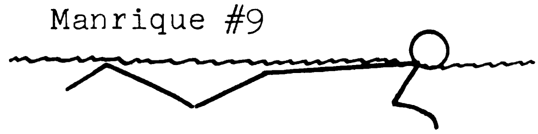
Leg recovery begins just before end of arm push back.

Jastremski #8



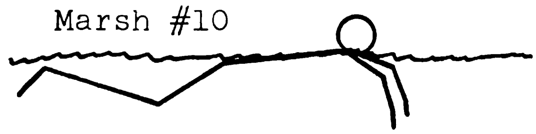
Leg recovery begins almost at end of arm push back. Very little hip bend until later.

Manrique #9



Leg recovery begins before end of arm push

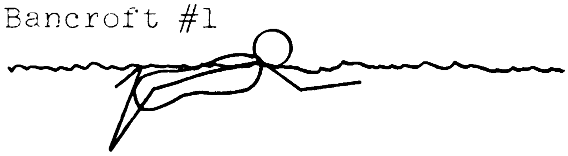
Marsh #10



Leg recovery begins just past the halfway point of arm pull, well before arm recovery.

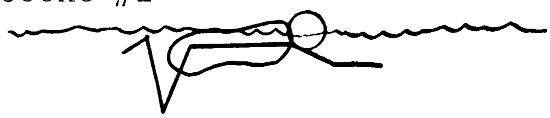
Figure 2.--Body Position at Beginning of Leg Kick.

Bancroft #1



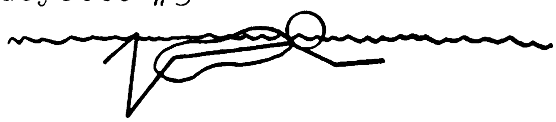
Heels recover beyond 90°, hip flexion angle is good, body rise and back extension is obvious.
Velocity: 1.14 Ft/Sec.

Cooke #2



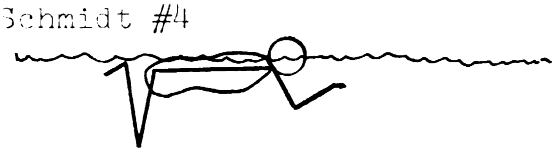
Heel recovery is average, hip fexion angle is fair.
Velocity: .82 Ft/Sec.

Goyette #3



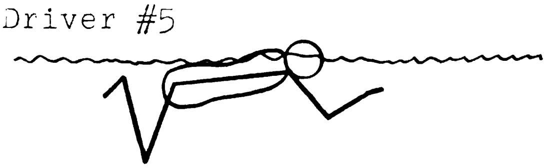
Heel recovery at 90°, hip flexion angle good. Slight body rise and back extension.
Velocity: 1.59 Ft/Sec.

Schmidt #4



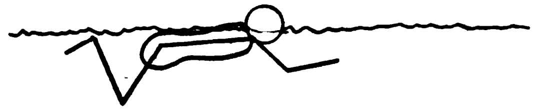
Heel recovery just short of 90°, hip flexion angle not good.
Velocity: 1.13 Ft/Sec.

Driver #5



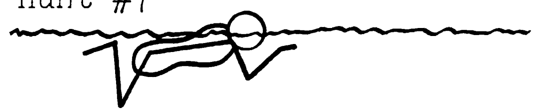
Heel recovery is average and so is hip flexion angle. Slight body rise.
Velocity 1.17 Ft/Sec.

Fetters #6



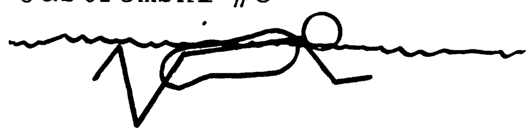
Heels recover well short of 90°, hip flexion angle is good.
Velocity: 1.66 Ft/Sec.

Hunt #7



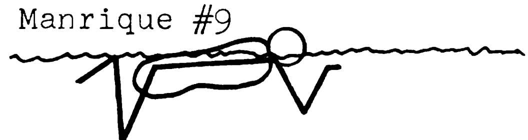
Heel recovery at 90°, hip flexion is good, slight body rise.
Velocity: 1.29 Ft/Sec.

Jastremski #8



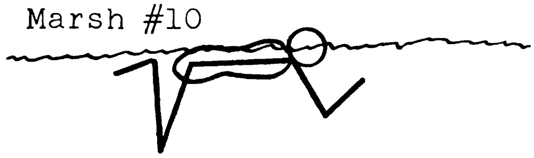
Heel recovery less than 90°, help flexion is good, slight body rise and back extension.
Velocity: 2.48 Ft/Sec.

Manrique #9



Heel recovery short of 90°, hip flexion is fair.
Velocity: 1.28 Ft/Sec.

Marsh #10



Heel recovery short of 90°, hip flexion is not good, no body rise.
Velocity: .78 Ft/Sec.

Figure 3.--End Leg Recovery Position.

Stroke Timing Measures

Another variable with a hypothetical relationship to mechanical efficiency, is The Amount of Stroke There is No Power While the Negative Leg Recovery Occurs. Goyette, with her standard breaststroke and early leg recovery, scored best of all 10 subjects (16.1%), while Hunt was second (27.2%) and top for males. He, too, has a fairly early leg recovery, enabling him to finish his leg recovery before much "no power" time has lapsed.

It is interesting to note that apparently the suggestions of Plummer (23) made in 1938, were followed. He suggested that the glide be shorter than the extra long one (6 to 8 feet) common then, because in this study, only one subject actually had a very long glide. All the men and most of the women begin their arm pull almost immediately after the finish of their leg kick, thus practically eliminating the glide. Several swimmers even started their arm pull during their leg kick, which gave them a negative or minus glide. It was therefore necessary to add 30% to all glide scores to keep them on the positive side in this variable.

Computer Results: First Trial, All 42 Variables

After assembling, the data were put into the Michigan State University Data Process Computer. The 42 variables were run through, once each for the following subject groups:

All 10 subjects, 6 men, 4 women, 5 Quick stroke, and 5 Standard stroke.

The correlation results are summarized on "Correlation Table: First Trial, All 42 Variables" (see Appendix B, Table 3). The three measures used as dependent variables for comparison criteria are: Average Velocity, Success Rank, and Fastest 100 Yd. Time. The correlation results achieving the significance level of 80% or above are underlined, and will hereafter be referred to as having reached significance. In the Correlation Tally section of this chart, the independent variables which reached significance are counted in the appropriate subject classification category.

In order to quickly read the correlation and data charts, some additional explanation of the mechanics of correlation are in order. The arbitrary value of most of the variables has been rated from best to worst, using speed as a correlation criteria. This rating symbol is indicated beside each variable, and is based on the following: If the higher numbers are best, the symbol is <; if low numbers are best, the symbol is >; and if the variable doesn't demonstrate a definite trend in either direction, both symbols are given <>.

Average Velocity, one of the correlation criteria for this first trial through the computer, has a symbol of < because the best Average Velocity is the highest number. All other variables which have the same rating symbol should theoretically correlate positively with this correlation criteria. The other two criteria (Success Rank and Fastest 100 Yd. Swimming Time) have the opposite symbol >, because in each of these measures, the best scores are the lowest numbers. When reading the correlation or data tables, a variable with a like symbol should correlate positively with the correlation criteria; while a variable with an unlike symbol will correlate negatively.

Velocity Correlation Results

The velocity data show interesting trends with respect to the different subject groups. Leg Velocity correlates very high with all three dependent variables for subjects swimming the standard stroke (Average Velocity .912, Success Rank -.859, and Fastest Time -.905). This may indicate the importance of a good leg kick, especially for swimmers using this type of stroke.

Arm Velocity correlated with all 10 subjects (Average Velocity .583, Fastest Time -.666), the women (Average Velocity .996, Success Rank -.977, Fastest Time -.995); and the standard stroke swimmers (Average Velocity .936, Success Rank -.900, Fastest Time -.932). Arm Velocity had the highest correlation scores of any velocity measure, and indicates the importance of a good arm pull for all swimmers.

Velocity Change (high velocity minus low velocity) reached a negative correlation for the women (Average Velocity .938, Success Rank -.886, Fastest Time -.884), and the standard stroke swimmers (Average Velocity .910, Fastest Time

-.912). This can probably be explained by the fact that the better swimmers, even though their average and lowest velocity were higher than the poorer swimmers, still had a greater difference between their low and high velocity points. Slower swimmers with a lower average and low velocity just didn't reach the high velocity speeds which would have increased their velocity difference too.

Velocity Variance (a measure of standard deviation from the swimmer's average velocity) correlated well with all 10 subjects (Average Velocity -.539, Success Rank .614, Fastest Time .525), with the women (Average Velocity -.876, Success Rank .882 Fastest Time .930), and the standard stroke swimmers (Success Rank .815). Therefore Velocity Variance appears to be an important measure, indicating that better swimmers in this study are able to keep their cyclic velocity fluctuations much more constant than the poorer swimmers.

The remaining velocity measures, Highest Velocity and Lowest Velocity, did not correlate significantly.

Stroke Co-ordination Results

Of these measures, Per cent of Stroke at Breath correlated significantly the most frequently. It correlated with all 10 subjects (Average Velocity .597, Fastest Time -.692), the 5 Quick stroke subjects (Fastest Time -.872), and the 5 standard stroke people (Average Velocity .767, Fastest time -.758). This measure indicates that better swimmers in this study tend to breathe later in the stroke. A possible reason for this is that the direction of arm thrust can be straight back from its start. Early breathers, however, usually waste part of their arm stroke by pressing down on the water, rather than straight back, in order to lift their head at that point. Another reasonable argument for later breating has to do with the chest muscles. In order to inhale, certain thoracic muscles must relax. If this muscle relaxation occurs during the arm press, one may wonder if the swimmer is able to pull his hardest during this time. It seems better for the inhalation and automatic thoracic relaxation to occur after the major arm press, or during arm recovery when fewer muscles are working.

The Per Cent of Stroke There is No Arm Thrust During the Negative Leg Recovery, reached significance only twice; once for the 6 men (Fastest Time .766), and once for the quick stroke swimmers (Fastest Time .902). It seems reasonable that a swimmer who has a small per cent of his stroke involved with the negative leg recovery after his arm pull is finished, should be able to prevent his velocity from dropping very low. Although this was more obvious for the men and the quick stroke subjects, it probably is important to all breaststroke swimmers.

Stroke Cycle Time correlated significantly only once --with all 10 subjects (Average Velocity -.574); indicating that for this study, the swimmers who have a faster stroke cycle time are generally faster than those with a slower stroke cycle time.

Neither a measure of the Per Cent of Stroke the Head is Out for the Breath, nor the Per Cent Glide in the Stroke correlated significantly. The fact that Per Cent Glide wasn't significant is very interesting. Some swimmers in this study actually had a minus glide, and it was necessary to add 30% to all subjects' Per Cent Glide scores to keep these scores positive. There is a great variance in how the amount of glide correlates with actual success in breaststroke swimming. Goyette, the best woman swimmer, had more than twice the glide of any male swimmer, whereas most of the other very good swimmers had short glides. In fact, Goyette and her team-mate, Cooke, were the only two subjects in this study who had relatively long glides. In view of this information, it would seem reasonable that unless a swimmer is able to keep his velocity from dropping off fast during the glide either through his inherent body build or swimming skill, he should shorten or eliminate his glide.

Body Position at End Leg Recovery Results

As a whole, this group of measures correlated significantly almost as many times as the strength measures did. Hip Flexion Angle was the most important measure in this group, correlating highest of these variables. It was a measure of how far the swimmer brought his knees up under his body at the end of his leg recovery, in terms of an angle. It reached significance for all 10 subjects (Average Velocity .601, Success Rank -.973, and Fastest Time -.904);

and the standard stroke swimmers (Average Velocity .805, and Fastest Time -.797). In evaluating this measure, it seems reasonable that a swimmer with a better hip flexion angle has less disturbance in the laminar flow of water around his body. He should be able to keep his velocity more constant than a swimmer with an abrupt hip flexion angle, and a poor score in this measure.

Knee-hip Angle measured from 180° was the next highest of these measures in significance, but since it was almost an exact duplication of the previous hip angle measure, it won't be discussed at this time.

Knee-Heel Line measured off 180° is an angle measure, and shows how close the heels are brought to the buttocks during leg recovery. This correlated best with women (Average Velocity .965, Success Rank -.980, Fastest Time -.933), but also reached significance with the Standard stroke (Success Rank -.817) and all 10 swimmers (Success Rank -.539). This probably indicates that swimmers who recover heels closer to buttocks have a better kick and nigher net velocity than swimmers who don't recover heels that far.

Back Drop Distance is a measure of the curvature of the spine at end of leg recovery. 'It correlated significantly with all 10 subjects (Success Rank -.510), 6 men (Success Rank -.791, Fastest Time -.666), and the Quick stroke swimmers (Success Rank -.976). The hypothesis of this measure is that the swimmer who had a greater Back

Drop Distance will have greater spinal curvature or extension. This spinal curve will allow the knees to remain back further during leg recovery, increasing body streamlining for better laminar flow.

Body Angle at End of Leg Recovery, was measured from a line dreawn through the swimmer's hip and shoulder. It correlated with the women (Success Rank .855, and Fastest Time .860), and standard stroke swimmers (Success Rank .757). This indicates that especially for those subject groups, the shoulders being higher than the hips probably helps increase body streamlining.

Other measures in this group did not correlate significantly, or else correlated low enough that they won't be discussed.

Strength Measure Results

Strength measures in general correlated highest of all. One measure, Leg Adduction Strength, correlated significantly with high scores more than any other single variable. Since it was important to every subject group, we may assume that Adduction Strength is essential to all breaststroke swimmers, regardless of stroke type or sex. It correlated with all 10 subjects (Average Velocity .699, Success Rank -.721, Fastest Time -.684), 6 men (Average Velocity .857, Success Rank -.745, Fastest Time -.721), 4 women (Average Velocity .892, Fastest Time -.943), 5 quick Stroke subjects (Average Velocity .917, Fastest Time -.779), and the 5 standard stroke swimmers (Average Velocity .786, Success Rank -.837, Fastest Time -.776).

Arm Pronator Strength correlated best with all 10 subjects (Average Velocity .536, Fastest Time -.508). Latissimus Strength correlated with all 10 subjects (Average Velocity .588, Fastest Time -.724), and the 5 quick stroke swimmers (Fastest Time -.809). This may indicate the importance of good overall arm strength for breaststroke swimmers in general, and especially for those who do the quick stroke.

Knee Extension Strength correlated with all 10 subjects (Average Velocity .476), and the women (Average Velocity .920, Fastest Time -.956). This demonstrates its value to good breaststroke swimmers also.

Average Strength, an average of all strength measures, correlated well with all 10 subjects (Average Velocity .788, Fastest Time -.748), the women (Average Velocity .845), and the 5 standard stroke swimmers (Average Velocity .805, Fastest Time -.809). This indicates the importance of average strength, or all these strength measures, for good breaststroke swimmers.

Flexibility Measure Results

Both the flexibility measures correlated significantly; Foot Outward Rotation rated highest. It scored with the women (Average Velocity -.910, Success Rank .956, Fastest Time .942), and the standard stroke swimmers (Success Rank .771). Ankle flexion was significant with all 10 subjects

(Success Rank -.503), the women (Success Rank -.848), and the 6 men (Fastest Time -.792). These results indicate that these specific flexibility measures are important for all breaststroke swimmers.

Anthropometric Measures

Of these measures reaching significance, Weight and Shoulder Width were highest. Weight correlated with all 10 subjects (Average Velocity .551, Fastest Time -.638), 6 men (Success Rank -.717, Fastest Time -.832), and the 5 Quick Stroke subjects (Fastest Time -.943). Shoulder width correlated with all 10 subjects (Average Velocity .575, Success Rank -.487, Fastest Time -.659), and the 5 Quick Stroke people (Average Velocity .782, Fastest Time -.783). However, the inter-correlation between these measures and the strength measures was also quite high.

Height correlated with all 10 subjects (Fastest Time -.474), and the 4 women (Average Velocity -.911, Fastest Time .917). Lower Leg Length only correlated with the 4 women (Average Velocity -.946, Success Rank .922, Fastest Time .895). All other anthropometric measures had low significance with the dependent variables and they won't be discussed here. They are more meaningful when combined with other measures, giving a more complete picture of the subject. This is done in Trial Two and in the Final Correlation through use of formulas.

Comparison of Sex Differences, Anthropometric Measures, and Stroke Style

There are some interesting facts with reference to sex differences in anthropometric measures, stroke cycle time, and amount of glide that this study brings out through the inter-correlation of the independent variables. This information considers the subjects' scores, and specific measures of inter-correlation. Stroke Cycle Time, and Per Cent Glide are the two criterion variables used to determine correlation with the sex and anthropometric measures because they are a fairly good objective method for determining the swimmer's style of stroke. For example, the standard stroke swimmers generally have a longer Stroke Cycle Time and Per Cent Glide than the quick stroke swimmers. Therefore by comparing the swimmer's anthropometric measures with these stroke style measures, a fair estimate may be made of his stroke style with reference to his sex or body type.

Women have a longer Stroke Cycle Time (Average is 32.9%) than the men (20.5% Average). In order to keep these percentages all positive, 30% has been added to all subjects, therefore in actuality, the average glide taken by these women is only about 3% of their entire stroke, and the men had a -11% average. This indicates that at least for these subjects, the glide is practically non-existent when swimming their fastest breaststroke over a short distance.

The taller and heavier the swimmer, the smaller Per Cent Glide he has in his stroke. For women, Height correlated with Per Cent Glide at -.548, and the men at -.931. Weight correlated with Per Cent Glide for women at -.997 and for men it was -.703. In this study, this finding may be explained by the fact that the bigger swimmer was also stronger, and used less glide than the smaller swimmer did. Another reason probably lies with additional water friction for his increased size.

Height has no significance for either sex with reference to Stroke Cycle Time. The heavier woman has a faster Stroke Cycle Time, but Weight alone wasn't significant for men on this measure.

Shoulder Width wasn't significant for the swimmers when compared to Per Cent Glide, and it wasn't significant for men on Stroke Cycle Time. Women swimmers with broader shoulders tend to have a shorter stroke cycle. Greater leg length for men in this study correlates with less glide; for women, the opposite is true, although not statistically significant at the 80% level of confidence.

Leg length wasn't significant for either sex when compared to stroke cycle time, although the trend was for longer leg length to mean longer stroke cycles.

Table 1.--Comparison of Glide and Stroke Cycle Time for Each Sex with Certain Anthropometric Measures

	Per Cent Glide Measure #10		Stroke Cycle Time Measure # 20	
	Women	Men	Women	Men
Height #23	-.548	-.931	-.245	.404
Weight #22	-.997	-.703	-.945	.417
Shoulder Width #31	-.380	.226	-.645	-.242
Leg Length #28	.377	-.778	.591	.389

Computer Results, Second Trial, 11 Combined Variables

After obtaining complete correlations for the 42 variables, some were combined, and some omitted, condensing the number of variables for this trial through the computer to eleven. Basis for omission was low correlation with the dependent variables or high inter-correlation with another variable. The strength measures were omitted from this trial run to concentrate on other variables. However, the strength measures were again included in the Final Computer Analysis.

Results of the Second Trial run through the computer are compiled "Correlation Table: 11 Variables" (see Appendix B, Table 4).

Most of the combined variables correlated quite well with the two dependent variables, Average Velocity and Success Rank. As a whole, the original 42 individual variables which correlated well the first time through the computer also correlated well when combined in a formula this time. The measures reaching significance most this time were: Weight, Waist size and Height, combined in a formula to represent body size. It correlated with all 10 subjects (Average Velocity .691, Success Rank -.493), the 4 women (Average Velocity .986, Success Rank -.847), 5 quick stroke people (Average Velocity .757, Success Rank -.813), and the 5 standard stroke subjects (Average Velocity .808). This may indicate that bigger swimmers are faster swimmers if the extra size also represents extra strength, as it did with these subjects.

Stroke Timing measures were next in importance for this trial run. A formula for Per Cent Stroke at Breath, and Per Cent Stroke No Arm Power and Negative Leg Recovery was significant for 3 of the 5 subject groups. This combination of measures representing stroke timing correlated with all 10 subjects (Average Velocity .588, Success Rank -.563), 6 men (Success Rank -.710), and the 5 standard stroke subjects (Average Velocity .785, Success Rank -.796). This tends to re-emphasize the importance of good integral stroke timing for all breaststroke swimmers.

Velocity measures, and those representing the Body Position at End of Leg Recovery, correlated significantly enough to suggest their importance to a good breaststroke too. Magnitude of Velocity, a measure composed of Leg and Arm Velocity, Glide and Low Velocity, correlated with all

10 subjects (Average Velocity .529, Success Rank -.519), 5 quick stroke people (Average Velocity .760) and the 5 Standard stroke subjects (Success Rank -.824). Uniformity of Velocity is a measure composed of Velocity Difference between low and high, and Velocity Variance or Standard Deviation. It correlated with all 10 subjects (Success Rank .588) and the 4 women (.929). Leg Position at the End of Leg Recovery, is a measure composed of Hip Flexion Angle and Knee-Heel Line. It correlated with all 10 swimmers (Success Rank -.599), the women (Average Velocity .893, Success Rank .866), and the 5 standard stroke people (-.854). Body position at the end of leg recovery is a formula composed of Body Rise, and Back Flexion or drop distance. It correlated with 6 men (Average Velocity .728, Success Rank -.800), and the 5 quick stroke people (Success Rank .863).

Final Correlation Results, 16 Variables

Discussion of Variables

When the data were put into the computer for the final time, 14 combined and two single variables were used. Final variables were selected on the basis of high previous correlation with the dependent variables, and low intercorrelations. The two dependent variables used for correlation criteria were Average Velocity, and Success Rank Within Sex. All 14 independent variables were calculated from formulas which combined two or more separate measures into one number representing the subjects' total score on the measures.

A system of "P" cards was used to obtain a Final Regression Solution on the data, including other statistics such as Multiple Correlation Coefficients, Regression Coefficients, Beta Weights, and a "t" test for the Beta Weights.

All 10 swimmers were used together as the only subject grouping, since it would have necessitated a high amount of separate data groupings to include all of the final 16 variables with a smaller number of subjects into a multiple regression correlation. It also meant that the other subject groups (6 men, 4 women, 5 quick stroke, and 5 standard stroke) used in the previous two runs through the computer were eliminated. No special conclusions with reference to a specific group can therefore be made for this final correlation, but they have been discussed in the two previous correlation trials.

One other item of importance is that a different method of figuring each subject's Rank of Success was used than for the previous two trials. This time it was based on success within the swimmer's sex, rather than on general success as it was before. Therefore, some of the rating numbers are very different from those previously used for each subject, and the correlations also are very different. In fact, the correlation between the two dependent variables used as evaluation criteria for this final run, Average Velocity and

Success Rank within Sex, is a -.907. The negative correlation is due to the obvious fact that practically all the men were faster swimmers than the women were, regardless of their actual success in swimming competition within their sex. However, it appears that the different measure of Success Rank actually tends to cloud the data or confuse the actual results, rather than clarify them. For example, the strength measures which have correlated very well previously, still correlated at the 95% level of confidence with Average Velocity (.718) but did not correlate with the new Success Rank measure (-.455). Other measures such as Leg Angles at end of Recovery, correlated equally with both dependent variables, but positive with Average Velocity (.948) and negative with this success rank measure (-.929), contrary to the way it correlated in the first trial as separate measures (see Appendix B, Table 3), or in the second trial as this identical formula. Therefore, in relating the results of this final trial, Average Velocity will be used as the major reference for the correlation criteria.

The Final Conclusions are in two parts: Simple Correlations, and the Final Regression Solution with related statistics. Results of the Simple Correlations are in Appendix B, Table 6 (Final Combined 16 Variables); and the Final Regression Solution in Appendix B, Table 7 (Final Regression Solution, All 16 Combined Variables).

Simple Correlations, Final Trial

All of the selected variables combined in a formula for the final trial run through the computer correlated high enough to reach significanct at an 80% level of confidence or higher, with one or both of the dependent variables. Since the simple correlation level for these final selected variables was so high, the actual significance of each is rated according to the level of confidence which may be expressed about that variable. In general, the original 39 variables having high correlation in the first trial run through the computer, also had high correlation with Average Velocity when combined in a formula for the final run.

Correlation at 99%.--The following combined variables correlated at the 99% level of confidence with Average Velocity: Foot Flexion (.844), Magnitude of Velocity (.857), Leg Angles at end of leg recovery (.948), Body position at end of leg recovery (.953), Body size (.867), Leg Length, foot area, Height (-.948), and Leg-Body position at end of leg recovery (-.797).

The Flexibility formula combined the two measures of flexibility which already correlated well in the first trial run, and this merely re-affirms their value in a good breaststroke swimmer.

Magnitude of velocity, combined Leg velocity, arm velocity and low velocity in the same formula as used in the second run through the computer, which correlated well then, too. This indicates that a swimmer should have a powerful leg kick, arm pull, and also a well-coordinated stroke to keep his low velocity point as high as possible.

Leg position at the end of recovery, combined Hip Flexion Angle, and knee flexion angle (measured from 180°) for an exact picture of the swimmer's leg recovery position. The two individual measures correlated well in the first trial, and correlated well again in the second trial when combined in this formula. This re-affirms previous discussion about the importance of a streamlined leg position during recovery, and that heels being close to buttocks then, probably adds to the leg kick velocity.

Body position at the end of recovery, was a measure representing shoulder rise, and back flexion or drop distance. The individual measures correlated well in the first trial, and also when combined in this formula for the second run through the computer. This re-affirms their addition to the streamlined body position, so necessary during leg recovery.

It was interesting to note that when the two previous formulas were combined into one measure on the entire Body and Leg position at End of Recovery, it correlated negatively with Average Velocity, but positively with Success Rank (.919). One possible reason is that there were too many individual stroke differences within this group of subjects for such all-inclusive measure to reach positive significance with Average Velocity.

Body size is an anthropometric measure composed of Weight, Height and Waist Width; and it also correlated well in this formula for trial #2. It shows that better breaststroke swimmers in this study had a small waist in relationship to their larger height and weight measures.

The other anthropometric measure was a formula for Leg Length, Foot area and Height, which corrolated negatively. This formula in trial two only correlated with the four women swimmers, so we might assume that this measure of foot size and leg length per height describes the thinner women better than the husky men; or that it is not very important in its contribution to a high breaststroke velocity.

Correlation at 95%.--Using Average Velocity as a correlation criteria, the following combined measures correlated at the 95% level of confidence: Strength (.718), Uniformity of Velocity (.724), and Stroke Timing (.686). The Strength formula combined Leg Adduction, Knee Extension, Latissimus and Forearm Pronator Strength together. These individual measures each correlated well in the first trial run through the computer and this re-emphasized their necessity for a high breaststroke swimming velocity.

Uniformity of Velocity combined a measure on the Difference between Low and High Velocity, and Velocity Variance (standard deviation from average velocity). Both measures correlated quite well in both the first and second computer runs, so this reaffirms the value of keeping the swimmer's velocity as uniform as possible during the entire stroke cycle.

The Stroke Timing formula combined a measure of Per Cent Stroke Complete at Breath, and Per Cent No Leg or Arm Power during Recovery. These measures correlated well individually during the first trial, and in this formula for the second trial. They show that for this study, the later breath and also minimal "no power" phase during recovery, both contribute to a high velocity.

Correlation at 90%.--An additional formula for Stroke Timing was the only variable in the final trial to reach correlation at the 90% level of confidence (.564). It combined Per Cent Stroke at Breath, and Per Cent No Power During Negative Leg Recovery, and Shoulder Extension Angle in almost the same formula as the previous Stroke Timing measure. The addition of Shoulder Extension Angle which didn't correlate well in the first trial, and wasn't used in the second trial, was the only change. In view of the lower correlation of Stroke Timing with its addition, this measure of Shoulder Extension Angle probably is not important or even relevant to a fast breaststroke velocity.

Correlation at 80%.--Two anthropometric measures correlated with Average Velocity at the 80% level of confidence. A formula for Body Size and Shape which combined Foot Area, Shoulder Width, Waist Width, Hip Width, and Waist Circumference was one (-.519); and a formula for Height-Weight was the other (.542). The negative correlation of the former measure indicates that high scores in these variables probably aren't as important for a fast breaststroke swimmer as many of the other measures taken in this study. It also may be because it is difficult to describe both a good female, and male breaststroke swimmer with the same set of anthropometric measures!

The Height-Weight measure indicates a possible advantage in breaststroke velocity of a taller person per unit of weight, than a shorter person per unit of weight.

One large formula combining five measures of velocity did not correlate with Average Velocity, although it did with Success Rank (.504). This may indicate the same difficulty as other all-inclusive formulas have had in correlating with the dependent variables. There are probably too many individual differences and too few subjects in this study to be able to utilize all those measures effectively in a correlation equation.

A discussion of the previous variables and how they correlated with Success Rank Within Sex will not be made here because of the repetition, and relative unimportance of an addition discussion of the same measures again.

Final Regression Solution Results

The results of the "P" card system of data analysis produced a Multiple Correlation Coefficient and set of related statistics for each group of seven independent and one dependent variables. All of these multiple correlation coefficients were well above .90 for every group of data. The Corrected Multiple Correlation Coefficients were also, so these will be the statistics quoted for each group of data.

Regression Equations and Corrected Correlation Coefficients.--The multiple regression equation for predicting x15, Average Velocity, from x6 Strength, x12 Body Size, x14 Height-Weight, x13 Leg Length-Foot Area-Height, x7 Magnitude of Velocity, and x8 Uniformity of Velocity is:

$$x15 = .4993 + .003x6 + .018x12 - .025x14 - .051x13 - .030x9 - .001x7 - .087x8.$$

The corrected correlation coefficient was .9405 ± .4761.

The multiple regression equation for predicting x15, Average Velocity, from x4 Body Size-Shape, x13 Leg Length-Foot Area-Height, x12 Body size, x14 Height-Weight, x8 Uniformity of Velocity, x10 Leg Angles at End Leg Recovery, and x11 Body Position at End Leg Recovery is:

$$x15 = -11.668 + .012x4 + .050x13 + .005x12 + .111x14 + .125x8 + 2.306x10 + 1.156x11.$$

The corrected correlation coefficient was .9709 ± .3352.

The multiple regression equation for predicting x15, Average Velocity, from x5 Foot Flexibility, x8 Uniformity of Velocity, x14 Height-Weight, x13 Leg Length, x12 Body Size, x11 Body Position at End of Leg Recovery, and x10 Leg Angles at end Leg Recovery is:

$$x15 = 10.841 - .156x5 - .128x8 - .058x14 - .098x13 + .015x12 - .456x11 + .270x10.$$

The corrected correlation coefficient was .9838 ± .2508.

The multiple regression equation for predicting x15, Average Velocity, from x6 Strength, x4 Body Size-Shape, x5 Foot Flexibility, x7 Magnitude of Velocity, x9 Stroke Timing, x11 Body Position at End Leg Recovery, and x10 Leg Angles at End Leg Recovery is:

$$x15 = -.384 - .001x6 + .002x4 - .162x5 - .002x7 + .064x9 + 1.332x11 + 1.580x10.$$

The corrected correlation coefficient was .9622 ± .381.

Significance of Beta Weights.--By using the "t" test for Beta Weights, the relative importance of each variable in its contribution to the whole multiple correlation coefficient for each group of data is given. The following beta weights reached the 80% level of confidence for their contribution to the coefficients when using either Average

Velocity, or Success Rank Within Sex as the correlation criteria: Magnitude and Uniformity of Velocity (2.866 and 3.130), Leg Bend-Body Position at End Leg Recovery (2.632, 2.680, 5.857), Body Size-Shape (5.239), Foot Flexibility (-.2359), Magnitude of Velocity (4.709), Uniformity of Velocity (-2.359), Leg Angles at End Leg Recovery, (2.2457, 1.892, -4.391), Body Position at End Leg Recovery (1.893), and Body Size (2.082).

We may probably assume that the previous measures each contributed a significant part in the total correlation with Average Velocity and/or Success Rank Within Sex in breaststroke swimming.

CHAPTER V

SUMMARY AND CONCLUSIONS

By using a camera to film ten mediocre to outstanding breaststroke swimmers under water, cyclic velocity, stroke co-ordination and body positions were accurately determined. The ten subjects swam their fastest breaststroke past, toward, then away from the camera for different views of their stroke, then certain Strength, Flexibility and Anthropometric measures were taken.

Most of the 42 separate measures comprising each subject's variables were put into the Michigan State University computer three times. For the first two trials, variables were put through once for each of the following groups: All 10 subjects, 6 men, 4 women, 5 quick stroke, and 5 standard stroke. Average Velocity and Success Rank, which was based on speed, were the dependent variables used for correlation.

The importance of each variable was determined statistically, thus measuring its contribution to the total stroke velocity.

On the basis of these data, the following conclusions seem justifiable:

1. Those swimmers who are able to keep their cyclic velocity more constant will be faster breaststroke swimmers

than those whose cyclic velocity has more fluctuation. The slower swimmer has more velocity variance within his stroke than the faster swimmer.

2. High arm velocity resulting from a strong arm pull is important to all breaststroke swimmers, including women, and swimmers doing the Standard stroke. Faster swimmers have a higher arm pull velocity than slower swimmers.

3. Unless a swimmer is built so that his velocity remains almost constant during his glide, he should minimize or eliminate the glide. A more continuous stroke is faster than a glide stroke over the short distance tested, if the swimmer's velocity drops off fast during his glide.

4. Breathing at a point very close to the end of the arm pull or later is better than breathing earlier in the arm pull. The faster swimmer breathes later in his stroke cycle than the slower swimmer does.

5. The faster swimmer has a smaller percentage of his stroke involved with leg recovery while there is no arm power against the water. This is probably because he begins leg recovery sooner, so he finishes sooner; before his velocity drops a great deal. The slower swimmer has a greater amount of his stroke during which neither his arms or legs are pushing against the water, causing a greater drop in velocity than the faster swimmer.

6. The further from 90° a swimmer's hip angle is at the end of leg recovery, the faster his average velocity.

The closer his hip flexion angle approaches 90° during leg recovery, the slower his net velocity.

7. Swimmers who have a greater extension of the lower back during leg recovery (greater drop distance), are able to keep their hip angle further from 90° than the swimmers whose back remains straight.

8. Shoulders being higher than hips at the end of leg recovery contributes to a more streamlined body position and faster velocity for some swimmers.

9. Recovering feet to a point almost at the buttocks contributes to a good kick and fast velocity. Some swimmers who don't recover feet that far have a lower net velocity.

10. Good ankle flexion and foot outward rotation flexibility are very important for a fast breaststroke swimmer. Those whose flexibility measures were lower, were usually slower swimmers.

11. High leg adduction strength was the most important strength measure taken in this study for breaststroke swimmers.

12. Knee Extension, Latissimus, and Arm Pronator strength are also very important and contribute to a high average velocity in that order.

13. A long leg length and large foot area per height is probably an asset to a high breaststroke velocity.

14. A greater height than weight ratio is probably an asset to breaststroke swimming success.

15. The length of the stroke cycle time is more closely related to the type of stroke (Quick or Standard) than velocity, although the faster stroke cycle time is usually associated with a higher velocity.

16. The women in this study have longer stroke cycle times and a greater per cent glide than men.

17. The larger and heavier a swimmer is, the greater his or her tendancy is toward the quick or jump stroke, with a faster stroke cycle time and shorter glide.

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APPENDIX A

ALL 42 VARIABLES--COMPUTATION AND EXPLANATION

Velocity Measures

1. Net Leg Velocity: The highest point of velocity change resulting from leg pressure, minus the swimmer's velocity at the point before leg kick began. This score was taken in the interim after the leg kick began, and before the arm pull started.
2. Net Arm Velocity: The highest velocity point after the end of the leg kick, resulting from the arm pull. The swimmer's velocity at the point before the arm pull was subtracted from this score.
3. Low Velocity: The slowest point of the entire stroke cycle. This occurred in all subjects during their leg recovery.
4. High Velocity: The fastest speed the swimmer attained during the entire stroke cycle.
5. Velocity Difference Between Low and High: The total difference in velocity fluctuations; highest velocity for the subject minus his lowest velocity.
6. Velocity Variation: The amount of variance from the subject's mean or average velocity. The formula for standard deviation was used for this computation:

$$S^2 = \frac{NEX^2 - (EX)^2}{N(N-1)}$$

N: Total number of frames that each subject took for his complete stroke cycle.

X: The velocity at each plotted point (every 4th frame)

19. Average Velocity: The swimmer's total distance traveled in one complete stroke cycle divided by his stroke cycle time. $V = \frac{s}{t}$

Stroke Timing and Co-ordination Measures

20. Stroke Cycle Time: The total frames, or time, that the swimmer took to complete one entire stroke cycle.

7. Per Cent Stroke Complete at Breath: The amount of time after the swimmer first began his arm pull, until his head was lifted out of the water for his breath, divided by his stroke cycle time.

8. Per Cent Stroke Head Out: The total time the swimmer's head was out of the water for his breath, divided into his stroke cycle time.

9. Per Cent Stroke No Arm Power and Negative Leg Resistance: A key to the deceleration factor of each breaststroke swimmer. A total of the time in the swimmer's stroke between the end of his arm pull until the start of his leg kick, divided into his stroke cycle time. (The time he was recovering both his legs and arms simultaneously; neither arms or legs creating a propulsive force.)

10. Per Cent Glide: This measure was the time from the point at which the leg kick finished until arm stroke began, divided into the total stroke time.

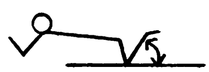
Body Position at End of Leg Recovery Measures

11. Knee Flexion Angle: This measure determined how close the heels were brought towards buttocks during the leg recovery. The angle was measured from a line drawn through the middle of the hip, knee and ankle.

12. Hip Flexion Angle: This measure determined how far the knees were brought under the body for leg recovery. It was measured from the angle of the hip joint by lines drawn through the swimmer's shoulder, hip, and knee.

13. Shoulder Extension Angle: A measure to determine how far the arms had recovered at this point in the stroke. It was measured from lines drawn through the swimmer's elbow, shoulder and hip.

14. Knee-heel Line: The angle was measured off 180°; it was another measure for Knee Flexion Angle.

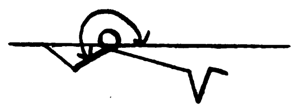


15. Knee Hip Line: The angles was measured off 180°; it was another measure for Hip Flexion Angle.

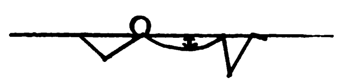
16. Body Rise Line: The angle was measured off 180°. It is an indication of how high the shoulders of a

swimmer rise above his hips during leg recovery.

17. Elbow-Shoulder Line: The angle was measured off 180°. This is another measure for shoulder extension.



18. Back Flexion, or Drop Distance: This measures the curve in the spine to compensate for hip flexion during the leg recovery. It enables hips to flex more without the knees being brought up under the body further. This measure is the distance between a straight line drawn through the center of the shoulder and hip; and the curved line that actually follows the spine. It is expressed in inches plus 1.00.



<u>Anthropometric Measures</u>

22. Weight: This was measured in pounds, to the nearest 1/4 pound.

23. Height: This was measured in inches, standing and without shoes.

24. Reciprocal Ponderal Index: It is a measure of largeness or ponderosity. The formula for computation was:

$$\text{Ponderal Index} = \frac{\text{Height}}{\sqrt[3]{\text{Weight}}}$$

25. Leg Length: This was measured in inches by subtracting sitting height from standing height.
26. Upper Leg Length: It was measured in inches, by subtracting sitting height from kneeling height.
27. Lower Leg Length: It was measured in inches from the heel to top of the knee.
28. Arm Length: It was measured in inches by subtracting the shoulder width from the arm span and dividing by 2.
29. Arm Span: It was measured in inches from fingertip to fingertip while the arms are extended straight out from the shoulders.
30. Foot Area: It was measured in inches by multiplying the foot length times the foot width.
31. Shoulder Width: It was measured in inches with a body calipers; one inch below the top of the shoulder.
32. Waist Width: It was measured in inches with the body calipers at the narrowest part above the hips.
33. Hip Width: It was measured in inches with body calipers at the widest part of the hips below the waist.
34. Waist Circumference: It was measured in inches around the narrowest part of the subject's waist with a tape measure.

Flexibility Measures

35. Foot Outward Rotation Angle: It was measured with a large protractor, while the subject was sitting, knees slightly bent. It was measured from the outside of feet, while the heels were together.

36. Ankle Flexion Angle: This was measured while the subject sat on the floor, his knees straight. The angle was taken from the floor, to the bottom of the swimmer's foot while flexing his angle as far as he could.

Strength Measures

NOTE: All of the strength measures were taken with a steel cable and one of the Michigan State Tensionometers. Each subject was given two trials, his best was used in the study.

37. Latissimus Strength: It was measured at a right angle off the shoulder, with the strap just below the elbow. The subject was reclining on his back, elbow pointed at the ceiling.

38. Forearm Pronator Strength: This was measured at a right angle off the shoulder with the strap just above subject's wrist; the subject flexed his arm in the position of his arm pull pattern.

39. Knee Extensor Strength: This was measured as the subject sat on the strength testing table. He extended his lower leg over the edge, strap just above the ankle,

and extended his knee against the cable which was anchored behind him.

40. Leg Adductor Strength: This was measured at right angles from a point immediately above the knee as the subject adducted his leg, while sitting on the table, knees slightly bent.

41. Average Strength Per Pound of Body Weight: It is figured by dividing the subject's weight into his strength score for each strength measure, then taking the average strength per pound of body weight from these.

Fastest Swimming Times

42. Fastest Time: This was the subject's fastest official swimming meet times on 100 and 200 yards. The figure for 100 yards was the primary measure used for a correlation criteria.

21. Success Rank: This was an arbitrary rank of the subject's success in breaststroke swimming based on the above times, and in consideration of the subject's sex. It was a rating number from 1 through 10.

APPENDIX B

TABLES

TABLE 2.--Master Data Table: 10 Subjects' Original 42 Variables.

	Velocity Measures						Stroke Timing				
	Net Leg Velocity (Ft/Sec)	Net Arm Velocity (Ft/Sec)	Lowest Velocity (Ft/Sec)	Highest Velocity (Ft/Sec)	Difference Between Low and High (Ft/Sec)	Velocity Variance (Standard Deviation)(Deviation Units)	Per Cent Stroke Complete At Breath (%)	Per Cent Stroke While Head Out for Breath (%)	Per Cent No Power and Negative Leg Recovery (%)	Per Cent Glide (30% Added to All)(%)	Knee Flexion Angle at End Leg Recovery (Degrees)
	1	2	3	4	5	6	7	8	9	10	11
1. Bancroft	3.516	1.80	1.144	6.580	5.316	3.165	.216	.549	.439	.210	26°
2. Cooke	4.523	1.33	0.823	5.753	4.930	4.086	.195	.397	.303	.391	19°
3. Goyette	4.943	1.67	1.593	6.537	4.940	1.201	.121	.374	.161	.596	21°
4. Schmidt	3.375	0.70	1.125	6.780	4.575	7.261	.127	.505	.364	.118	23°
5. Driver	4.830	1.64	1.170	7.050	6.360	5.094	.238	.655	.382	.088	30°
6. Fetters	3.480	1.72	1.680	6.800	5.120	3.192	.176	.493	.504	.241	61°
7. Hunt	5.400	1.88	1.290	7.407	6.116	3.670	.242	.567	.272	.249	39°
8. Jastremski	2.746	2.17	2.480	6.840	4.360	1.585	.522	.412	.334	.245	45°
9. Manrique	4.730	2.97	1.280	6.900	5.940	2.998	.384	.512	.371	.210	20°
10. Marsh	5.460	2.10	.780	7.140	6.360	4.456	.259	.511	.345	.198	22°

	Anthropometric Measures										
	Weight (Lbs)	Height (Inches)	Reciprocal Ponderal Index (Units of Ponderosity)	Leg Length (Inches)	Upper Leg Length (Inches)	Lower Leg Length (Inches)	Arm Length (Inches)	Arm Span (Inches)	Foot Area (Sq. In.)	Shoulder Width (Inches)	Waist Width (Inches)
	22	23	24	25	26	27	28	29	30	31	32
1. Bancroft	140.0	65.0	12.524	29.5	14.0	15.5	23.4	65.3	35.6	18.5	09.7
2. Cooke	131.0	65.0	12.795	31.7	15.2	16.5	26.2	68.5	35.7	16.3	09.5
3. Goyette	117.0	65.5	13.395	32.2	16.0	16.3	25.3	67.0	33.3	16.5	08.5
4. Schmidt	144.8	68.0	12.952	33.0	15.8	17.2	25.3	67.0	37.5	16.5	09.5
5. Driver	190.0	74.3	12.913	37.5	17.5	20.0	28.4	74.0	49.5	17.5	11.4
6. Fetters	134.0	67.5	13.184	33.0	17.0	16.0	25.3	67.0	45.0	16.8	10.5
7. Hunt	163.0	67.5	12.363	32.3	17.3	15.0	24.9	67.5	37.9	17.8	11.5
8. Jastremski	170.0	69.3	12.519	33.2	15.7	17.5	25.7	70.0	43.0	19.3	11.4
9. Manrique	158.0	69.0	12.754	33.2	15.7	17.5	25.7	70.3	43.0	19.0	11.5
10. Marsh	157.8	71.5	13.241	36.0	16.5	19.5	28.6	74.0	46.3	17.3	11.4

Body Position--End Leg Recovery							Correlation Criteria	Stroke Timing	Correlation Criteria
Hip Flexion Angle at End Leg Recovery + 90° (Degrees)	Shoulder Extension Angle at End Leg Recovery (Degrees)	180° Knee-Heel Angle at End Leg Recovery (Degrees)	180° Knee-Hip Angle at End Leg Recovery (Degrees)	180° Hip-Shoulder End Leg Recovery (Degrees)	180° Shoulder Elbow Angle End Leg Recovery (Degrees)	Back Extension or Drop Distance End Leg Recovery (Inches)	Average Velocity (Ft/Sec)	Stroke Cycle Time (Seconds)	Success Rank (Based on Speed)
12	13	14	15	16	17	18	19	20	21
45	159°	97°	122°	169°	179°	1.0762	4.469	1.000	3.0
69	148°	83°	112°	172°	204°	0.8746	4.057	1.500	7.0
57	138°	90°	112°	163°	209°	0.7890	4.205	1.917	2.0
79	141°	85°	110°	177°	216°	0.9089	3.444	1.167	10.0
62	129°	82°	112°	174°	226°	0.9131	4.762	1.000	4.0
50	128°	59°	121°	170°	224°	0.8629	4.383	.667	9.0
40	104°	90°	129°	170°	245°	0.8549	4.702	1.000	5.0
52	113°	76°	122°	174°	241°	1.0879	4.973	.583	1.0
64	105°	85°	106°	170°	241°	0.8992	4.264	.917	8.0
71	124°	76°	098°	178°	239°	0.9022	4.685	.917	6.0

		Flexibility		Strength					Correlation Criteria	Distance Traveled In One Stroke
Hip Width (Inches)	Waist Circumference (Inches)	Foot Outward Rotation (Degrees)	Ankle Flexion	Latissimus Strength (Lbs/Lb. Body Weight)	Forearm Pronator Strength (Lbs/Lb. Body Weight)	Knee Extensor Strength (Lbs/Lb. Body Weight)	Leg Adductor Strength (Lbs/Lb. Body Weight	Average Strength (Lbs/Lb. Body Weight)	Fastest 100 Yd. Time (Seconds)	(Ft.) Distance Traveled in One Stroke
33	34	35	36	37	38	39	40	41	42	**Extra**
14.0	28.5	180°	85°	.520	.275	0.875	.557	.575	68.9	4.4690
12.8	26.5	200°	77°	.516	.271	0.875	.557	.562	73.2	6.0855
13.3	23.0	200°	80°	.385	.222	0.902	.642	.500	69.6	8.0209
14.0	27.0	220°	77°	.431	.255	0.679	.310	.419	81.9	4.0190
12.9	33.5	200°	74°	.948	.500	0.889	.532	.717	62.3	4.7620
12.5	30.5	210°	57°	.437	.515	1.440	.355	.687	72.8	2.9263
13.2	31.5	210°	75°	.589	.257	0.694	.672	.553	63.6	4.7020
12.5	31.5	210°	77°	.999	.550	1.500	.825	.800	59.3	2.8993
12.5	31.0	180°	77°	.999	.511	0.788	.324	.656	67.2	3.8852
13.4	32.0	200°	67°	.836	.543	1.000	.824	.651	65.0	3.1120

TABLE 3.--Correlation Table: First Trial, All 42 Variables.

	Measures	Value	Average Velocity #19 < All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke	
1.	Net Leg Velocity	< 1	.160	-.192	.380	-.341	.912	
2.	Net Arm Velocity	< 2	.583	-.442	.906	-.239	.936	
3.	Low Velocity	< 3	.393	.361	.258	.523	.281	
4.	High Velocity	< 4	.447	.253	-.214	.225	.458	
5.	Velocity Change	> 5	.405	-.240	.938	-.477	.910	
6.	Standard Deviation	> 6	-.539	-.076	-.876	-.393	-.486	
7.	% Stroke at Breath	< 7	.597	.372	.544	.579	.767	
8.	% Stroke Head Out	> 8	.231	-.063	-.086	-.735	.486	
9.	% Stroke No Arms, Neg. Leg	> 9	.012	-.527	-.080	-.593	-.140	
10.	% Glide	<>10	-.069	-.122	.492	.331	.011	
11.	Knee Flexion Angle	> 11	.394	.071	.204	.159	.659	
12.	Hip Flexion Angle	< 12	.601	.161	.943	.006	.805	
13.	Shoulder Extension	> 13	-.499	.091	.536	-.120	-.665	
14.	180° Knee-Heel	< 14	.088	.195	.965	-.096	.688	
15.	180° Knee-Hip	< 15	.528	.268	.968	.136	.804	
16.	180° Hip Shoulder	> 16	-.034	.558	.779	.663	-.366	
17.	180° Shoulder Elbow	<> 17	.392	.206	-.770	.268	.585	
18.	Back Drop Distance	< 18	.342	.655	.266	.585	-.176	
20.	Stroke Cycle Time	<> 20	-.574	.158	.168	-.513	-.243	20
22.	Weight	<> 22	.551	.618	-.481	.648	.546	
23.	Height	<> 23	.421	.354	-.911	.391	.441	
24.	Ponderal Index	> 24	-.274	-.363	-.763	-.227	-.309	
25.	Leg Length	< 25	.307	.268	-.797	.277	.436	
26.	Upper Leg Length	> 26	.305	.084	-.574	.021	.782	
27.	Lower Leg Length	< 27	.219	.251	-.946	.394	.138	
28.	Arm Length	< 28	.272	.267	-.495	.309	.408	
29.	Arm Span	< 29	.451	.305	-.401	.361	.554	
30.	Foot Area	< 30	.485	.043	-.725	.165	.489	
31.	Shoulder Width	> 31	.575	.200	.590	.268	.782	
32.	Waist Width	< 32	.635	.381	-.183	.309	.657	
33.	Hip Width	< 33	-.413	.302	-.185	-.015	-.708	
34.	Waist Circumference	> 34	.627	.539	-.078	.423	.596	
35.	Foot Outward Rotation	< 35	-.086	.593	-.910	.589	-.307	
36.	Ankle Flexion	< 36 <	-.133	.370	.775	.120	-.479	
37.	Latissimus Strength	< 37	.588	.298	.295	.392	.667	
38.	Arm Pronator Strength	< 38	.536	-.041	.032	.311	.508	
39.	Knee Extension Strength	< 39	.476	.236	.920	.560	.349	
40.	Leg Adduction Strength	< 40	.609	.857	.892	.917	.786	
41.	Average Strength	< 41	.788	.399	.845	.669	.805	

*80% Level of Confidence, n = 10 -- .470; n = 6 -- .665; n = 5 -- .740; n =

	Success Rank #21 >						Fastest 100 Yard Time #42 Σ					Correlation Tally @ 80% Confidence					
All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke		All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke	All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke	Total
Velocity																	
.068	.281	-.317	.519	-.859	1	-.250	.003	-.498	.125	-.905					3	3
-.251	.191	-.977	.235	-.900	2	-.666	.011	-.995	-.312	-.932	2		3		3	8
-.431	-.488	-.480	-.377	-.609	3	-.368	-.244	-.317	-.441	-.294						0
-.056	-.133	-.046	.379	-.223	4	-.456	-.309	.250	-.327	-.467						0
.038	.322	-.886	.532	-.569	5	-.444	.055	-.884	.279	-.912			3		1	4
.614	.243	.882	.503	.815	6	.525	.088	.930	.461	.482	3		3		1	7
Stroke Coordination																	
-.396	-.613	-.366	-.463	-.299	7	-.692	-.604	-.456	-.872	-.758	2			5	2	9
.066	.121	.012	.315	-.063	8	-.225	-.036	.213	.684	-.494						0
.318	.588	.118	.413	.550	9	.142	.766	.211	.902	.135		1		1		2
-.253	.124	-.473	-.130	-.456	10	.060	.233	-.604	-.101	-.004						0
Body Position at End of Leg Recovery																	
-.011	.034	-.347	.132	-.271	11	-.201	.344	-.095	.234	-.656						0
-.543	-.145	-.973	-.416	-.690	12	-.496	.005	-.904	.253	-.797	3		3		2	8
-.054	.113	-.435	-.353	.359	13	.550	.258	-.425	.421	.661	1					1
-.539	-.342	-.980	-.537	-.817	14	-.230	-.606	-.933	-.192	-.680	1		3		1	5
-.498	-.266	-.896	-.427	-.593	15	-.426	-.087	-.928	.188	-.790	2		3		2	7
.300	-.425	.855	-.134	.757	16	.032	-.452	.860	-.597	.365			2		1	3
.156	-.317	.722	.349	-.120	17	-.475	-.476	.678	-.455	-.583	1					1
-.510	-.791	-.253	-.976	.590	18	-.318	-.666	-.135	-.562	.172	1	2		1		4
Stroke Coordination																	
-.031	.180	-.176	.073	-.291	20	.368	-.104	-.299	.295	.243	1					1
Anthropometric Measures																	
-.211	-.717	.484	-.403	-.110	22	-.638	-.832	.594	-.943	-.553	2	2		1		5
-.004	-.331	.769	.229	-.183	23	-.474	-.429	.917	-.515	-.457	1		2			3
.315	.544	.038	.751	-.216	24	.341	.586	.042	.434	.292				1		1
.116	-.179	.740	.405	-.261	25	-.350	-.261	.709	-.311	-.454						0
.221	.128	.491	.679	-.501	26	-.279	.148	.463	.126	-.791					2	2
.009	-.242	.922	.103	-.078	27	-.295	-.338	.895	-.551	-.157			3			3
.103	-.153	.612	.308	-.265	28	-.316	-.257	.396	-.339	-.420						0
-.053	-.286	.565	.161	-.340	29	-.533	-.434	.314	-.536	-.566	1					1
.109	.030	.757	.565	-.177	30	-.452	.052	.807	-.126	-.502	1					1
-.487	-.495	-.634	-.607	-.408	31	-.659	-.558	-.482	-.649	-.783	3				2	5
-.038	-.530	.350	.206	-.152	32	-.674	-.777	.299	-.597	-.655	2	1				3
-.035	-.087	-.008	-.414	.599	33	.433	-.240	.277	.134	.699						0
-.040	-.504	.155	.249	-.101	34	-.612	-.607	.205	-.522	-.598	2					2
Flexibility																	
.385	-.386	.956	.019	.771	35	.164	-.133	.942	-.219	.313			3		1	4
-.503	-.614	-.848	-.711	-.055	36	-.041	-.792	-.701	-.413	.478	1	1	1			3
Strength																	
-.269	-.520	-.094	-.194	-.333	37	-.724	-.664	-.204	-.809	-.675	2			1		3
.009	-.001	.137	.385	-.265	38	-.508	.085	.075	-.367	-.520	2					2
-.242	-.188	-.829	-.132	-.613	39	-.315	.118	-.956	-.199	-.354	1		2			3
-.721	-.745	-.833	-.673	-.837	40	-.684	-.721	-.943	-.779	-.776	3	3	2	2	3	13
-.366	-.495	-.675	-.199	-.577	41	-.748	-.309	-.813	-.631	-.809	2		1		2	5

4 -- .835.

TABLE 4.--Correlation Table: 11 Combined Variables*

	Correlation Tally @ .20						Average Velocity #19					Success Rank #21				
	All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke	Total	All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke	All 10 Subjects	6 Men	4 Women	5 Quick Stroke	5 Standard Stroke
1. **Magnitude** of Velocity $1 + 2 + (10 \cdot 3)$	2			1	1	4	.520	.344	.427	.760	.261	-.519	-.501	-.740	-.384	-.824
2. Uniformity of Velocity $5 + 6$	1		1			2	-.316	-.145	-.825	-.600	-.058	.588	.282	.929	.576	.660
3. Stroke Timing $\frac{7}{9}$	2	1			2	5	.588	.499	.610	.677	.785	-.563	-.710	-.679	-.560	-.796
4. Leg Position at End Leg Recovery $12 + 14$	1		2		1	4	.355	.254	.893	.222	.268	-.599	-.343	-.866	-.521	-.854
5. Body Position at End Leg Recovery $16 + 18$		2		1		3	.266	.728	-.099	.562	-.017	-.193	-.800	.344	-.863	.699
6. Foot Area, Weight $\frac{30}{22}$						0	-.049	-.468	.192	-.428	.456	.330	.606	-.379	.625	-.393
7. Body Size $\frac{22 \cdot 23}{32}$	2		2	2	1	7	.691	.553	.986	.757	.808	-.493	-.595	-.847	-.813	-.474
8. Leg Length and Height $\frac{25 + 30}{23}$			1			1	.429	-.108	-.799	-.163	.729	.210	.223	.939	.564	-.082
9. Body Size $\frac{23}{32}$	1	1				2	.509	-.635	.297	-.662	-.379	.135	.779	-.544	.606	-.235

*.20 Significance, n = 10 -- .470; n = 6 -- .665; n = 5 -- .740; n = 4 -- 835.

TABLE 5.--Ten Subjects' Calculations of Scores for Final Computer Trial.

Final Combined 16 Variables	<	<	<	<	<	≤	≤	≥	<	<	<>	<>	<	<	>	<
Subjects	Magnitude Uniformity of Velocity $\frac{1+2+3+4}{6}$	Stroke Timing $\frac{7}{9\cdot 13}$	Leg Bend, Body Position at End Leg Recovery 12 + 14 + 16 + 18	Body Size, Shape $\frac{30\cdot 31\cdot 34}{33(33-32)}$	Foot Flexibility 35·36	Strength 40(37 + 38 + 39)	Magnitude of Velocity 1 + 2 + (10·3)	Uniformity of Velocity 5 + 6	Stroke Timing $\frac{7}{9}$	Leg Angles at End Leg Recovery 12 + 14	Body Position at End Leg Recovery 16 + 18	Body Size $\frac{22\cdot 23}{32}$	Leg Length, Foot Area, Height $\frac{25+30}{23}$	Height-Weight $\frac{23}{32}$	Velocity 19	Success Rank Within Sex
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bancroft	04.1200	03.0945	35.6520	031.1795	15.3000	093.0190	16.7560	08.4840	04.9200	2.32	2.7662	093.8144	10.015	46.428	4.469	08.0
Cooke	03.0418	04.3484	29.8660	036.7580	15.4000	092.5734	14.0830	09.0160	06.4350	1.94	2.5946	089.6315	10.369	49.618	4.057	05.5
Goyette	12.2756	05.4460	30.8200	027.5413	16.0000	096.8778	22.5430	06.1410	07.5150	2.13	2.4190	091.1647	10.000	55.982	4.275	10.0
Schmidt	01.6499	02.4744	29.7590	026.5179	16.9400	042.3150	15.3260	11.8360	03.4890	1.86	2.6789	082.3157	10.367	46.896	3.444	01.6
Driver	02.8837	04.8297	30.8710	149.9710	14.8000	124.3284	18.1700	11.4540	06.2300	2.01	2.6531	123.3333	11.709	39.105	4.762	08.0
Fetters	04.2857	02.7281	29.2290	092.2320	11.9700	084.9160	22.0000	08.3120	03.4920	1.89	2.5629	086.1428	11.555	50.373	4.383	01.6
Hunt	04.3534	08.5548	33.2490	094.6993	15.7500	103.4880	20.1800	09.7869	08.8990	2.30	2.5549	095.6782	10.400	41.411	4.702	06.4
Jastremski	08.9987	13.8307	32.2190	190.1225	16.1700	251.5425	29.7160	05.9450	15.6280	2.04	2.8279	102.8947	10.995	40.764	4.973	10.0
Manrique	05.2968	09.8575	30.7920	202.6160	13.8600	074.4520	20.5000	08.9380	10.3500	2.01	2.5992	094.8000	11.043	43.670	4.264	03.3
Marsh	03.4739	06.0542	29.3020	096.6734	13.4000	196.0296	15.2700	10.8160	07.5070	1.85	2.6822	099.0964	11.580	45.253	4.685	04.9

TABLE 6.--Final Trial: Simple Correlations of 16 Combined Variables.

Variables		Correlations	
		Velocity	Success Rank
1.	Magnitude-Uniformity of Velocity $\frac{1 + 2 + 3 + 4}{6}$	-.298	.504[d]
2.	Stroke Timing $\frac{7}{9 \cdot 13}$	.564[c]	-.299
3.	Leg Bend-Body Position at End Leg Recovery 12 + 14 + 16 + 18	-.797[a]	.919[a]
4.	Body Size-Shape $\frac{30 \cdot 31 \cdot 34}{33 \cdot (33-32)}$	-.519[d]	.746[b]
5.	Foot Flexibility 35·36	.884[a]	-.924[a]
6.	Strength 40(37 + 38 + 39)	.718[b]	-.455
7.	Magnitude of Velocity 1 + 2 + (10·3)	.857[a]	-.736[b]
8.	Uniformity of Velocity 5 + 6	.724[b]	-.864[a]
9.	Stroke Timing $\frac{7}{9}$	.686[b]	-.443
10.	Leg Angles at End Leg Recovery 12 + 14	.948[a]	-.929[a]
11.	Body Position at End Leg Recovery 16 + 18	.953[a]	-.975[a]
12.	Body Size $\frac{22 \cdot 23}{32}$	.867[a]	-.700[b]
13.	Leg Length-Foot Area-Height $\frac{25 + 30}{23}$	-.948[a]	.985[a]
14.	Height-Weight $\frac{23}{22}$	.542[d]	-.703[b]
15.	Average Velocity 19	1.000	-.907[a]
16.	Success Rank Within Sex New measure this trial		1.000

[a] Significance at 99% (.01)
[b] Significance at 95% (.05)
[c] Significance at 90% (.10)
[d] Significance at 80% (.20)

TABLE 7.--Final Regression Solution, All 16 Combined Variables.

Dependent Variable	Independent Variables	Corrected Multiple Correlation Coefficients	Standard Error of Estimate	Regression Coefficients	Standard Error of Coefficients	Beta Weights	Standard Error or Betas	"F" Test for Betas	"t" Test for Betas
X15 =	0,6,12,14,13,9,7,8	.0495	.4761						
	0			4.993	7.044			.503	- .7894
	6			.003	.010	.157	.471	.112	1.494
	12			.018	.021	- .232	.271	.733	.486
	14			- .025	.072	- .123	.363	.115	.315
	13			- .051	.047	-1.005	.938	1.148	1.001
	9			- .030	.134	- .088	.395	.050	.710
	7			- .001	.067	- .008	.370	.005	1.316
	8			- .087	.206	- .219	.515	.181	.665
X15 =	0,4,13,12,14,8,10,11	.9709	.3352						
	0			-11.668	14.781			.623	- .305
	4			.012	.008	.700	.469	2.232	- .078
	13			.050	.103	.989	2.034	.237	.521
	12			.005	.017	.070	.221	.099	-1.121
	14			.111	.110	.554	.553	1.002	- .037
	8			.125	.176	.313	.441	.504	.378
	10			2.306	1.753	1.096	.833	1.731	1.308
	11			1.156	1.740	.695	1.045	.442	1.893 *
X15 =	0,5,8,14,13,12,11,10	.9838	.2508						
	0			10.841	6.939			2.441	1.562
	5			- .156	.066	- .554	.235	5.564	-2.359 *
	8			- .128	.056	- .320	.130	5.223	-2.285 *
	14			- .058	.040	- .290	.198	2.140	-1.463
	13			- .098	.056	-1.944	1.119	3.021	-1.738
	12			.015	.011	.193	.135	2.036	1.427
	11			- .456	1.126	.274	.677	.164	- .405
	10			.270	.681	.128	.324	.157	.397
X15 =	0,6,4,5,7,9,11,10	.9622	.381						
	0			- .384	1.260			.093	- .305
	6			- .001	.013	- .046	.587	.006	- .078
	4			.002	.005	.135	.260	.271	.521
	5			- .162	.145	- .576	.514	1.257	-1.121
	7			- .002	.042	- .008	.230	.001	- .037
	9			.064	.168	.187	.496	.143	.378
	11			1.332	1.018	.800	.612	1.711	1.308
	10			1.580	.834	.751	.397	3.583	1.892 *

X16 =	0,1,7,8,2,9,3,10	.9855	3.015						
	0			-28.573	30.241			.893	- .945
	1			1.119	.680	.221	.134	2.708	1.646
	7			- .306	.464	- .132	.200	.436	- .660
	8			.563	1.234	.111	.243	.209	.457
	2			- .167	2.244	- .035	.465	.006	- .075
	9			.520	2.100	.121	.489	.061	.248
	3			1.823	.680	.454	.169	7.181	2.680 *
	10			-14.561	5.926	- .546	.222	6.038	-2.457 *
X16 =	0,9,2,3,6,1,5,12	.9357	6.265						
	0			-16.251	39.927			.166	- .407
	9			4.977	6.382	1.159	1.486	.608	.780
	2			- 2.676	4.781	- .555	.991	.313	- .560
	3			1.603	.871	.399	.217	3.388	1.841
	6			- .144	.154	- .528	.563	.879	- .937
	1			.384	.923	.076	.182	.173	.416
	5			- 2.894	1.388	- .812	.389	4.352	-2.086
	12			.109	.235	.108	.235	.213	.461
X16 =	0,12,6,3,2,1,5,10	.9923	2.193						
	0			-35.139	14.021			6.281	-2.506 *
	12			.175	.084	.175	.084	4.336	2.082 *
	6			- .041	.037	- .148	.136	1.188	-1.090
	3			1.807	.308	.450	.077	34.302	5.857 *
	2			.421	.570	.087	.118	.545	.738
	1			.848	.271	.167	.053	9.797	3.130 *
	5			.042	.561	.012	.157	.006	.074
	10			-16.970	3.865	- .636	.145	19.279	-4.391 *
X16 =	0,7,1,2,3,6,4,8	.9947	1.833						
	0			- 5.985	15.470			.150	- .387
	7			- .979	.208	- .423	.090	22.175	-4.709 *
	1			1.229	.421	.242	.085	8.214	2.866 *
	2			.095	.451	.020	.093	.045	.211
	3			.852	.324	.212	.081	6.929	2.632 *
	6			- .020	.030	- .073	.108	.456	- .675
	4			.070	.013	.315	.060	27.447	5.239 *
	8			- .627	.589	- .124	.116	1.133	-1.065
X16 =	0,8,4,3,2,5,6,1	.9351	6.293						
	0			-24.725	51.272			.233	- .482
	8			- .586	2.665	- .116	.526	.048	- .220
	4			.072	.089	.326	.398	.671	.819
	3			1.355	1.105	.338	.275	1.505	1.227
	2			.058	1.699	.012	.352	.001	.034
	5			- .491	2.170	- .138	.608	.051	- .227
	6			- .075	.102	- .273	.371	.542	- .736
	1			.710	1.495	.140	.295	.226	.475

*Significant at 80% Level of Confidence 1.8856