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EFFECTS OF STROKE PATTERN ON POWER OUTPUT IN FREESTYLE SWIMMING

presented by

MARK ANDREW DZIAK

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of the requirements for the

M.S. degree in KINESIOLOGY

Eugene W. Brown
Major Professor's Signature

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EFFECTS OF STROKE PATTERN ON POWER OUTPUT IN FREESTYLE SWIMMING

By

Mark Andrew Dziak

A THESIS

Submitted to
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ABSTRACT

EFFECTS OF STROKE PATTERN ON POWER OUTPUT IN FREESTYLE SWIMMING

By

Mark Andrew Dziak

This study explored the amount of swimming power generated by two different freestyle (front crawl) stroke patterns. The two stroke patterns are a curvilinear S-shape pull and a straight-path I-pull. Power was measured by having the athletes swim against the resistance of a Power Rack, a weight and pulley system that allows for in-water power training for swimmers. Fifteen experienced swimmers (eight males and seven females) participated in this study. Each participant swam 18 trials – nine with each of the two stroke styles. Dependent and independent t-tests were calculated to find the potential differences between population groups. There were 12 results that gave a statistical difference ($t = 0.05$) among groups: the I-Stroke produced more power than the S-Stroke for the entire population at resistance level 1, and for males at resistance levels 1 and 2; freestylers produced more power than non-freestylers for the I-Stroke at resistance levels 1, 2, and 3; males produced more power than females at each resistance level for each stroke style. The power results were also correlated with anthropometric measures of height, weight, and arm length. In this study, swimming power correlates best with weight. This study cannot say that one stroke is better then the other but the data indicates that swimmers generate more power with the I-Stroke more often throughout the study. The research does open up the possibility for future studies to further explore the role of stroke style on power output.

DEDICATION

To my wonderful wife, Dorothee: Thank you for the continued love and support during this project. It would not have been completed without your inspiration

ACKNOWLEDGEMENTS

I'd like to recognize my committee of Eugene Brown, Gail Dummer, and Deborah Feltz. They were a great help in the completion of the research and the project.

I would like to thank my parents for their support throughout the years and always believing in me.

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CHAPTER 1 – INTRODUCTION

Overview and Significance of the Problem

Swimming stroke technique has evolved as scientific principles of biomechanics and physiology have been applied to the sport. The pioneer and leader of applying science to swimming was James "Doc" Counsilman, the late swimming coach of Indiana University. His book The Science of Swimming, first published in 1968, provided scientific insight into the sport and laid the basis for research that continues to this day. One of Counsilman's findings was the pattern the hand made in the water during the freestyle or crawl stroke. Prior to Counsilman's work, there was not much science used to study the mechanics of stroke technique. Counsilman observed that the hands and arms of top swimmers did not follow a straight path through the water, which was the conventional wisdom of the day, but rather their hands and arms performed a series of sculls. This sculling motion resulted in the arm following a more S-shaped pattern with respect to the body as the arm and hand moved through the water. Stroke patterns vary from individual to individual, but to this day, the S-shape is seen and taught as the most effective pull.

A report by Ito (2004) indicated that the S-Pull may not be the most effective pull. Shinichiro Ito, a mechanical engineer with the National Defense Academy in Yokosuka, Japan, first analyzed the swim patterns in turtles. He found that to maximize speed, turtles use a straight pull while to maximize efficiency turtles use a more S-shaped fin pattern. Subsequently, Ito used computer modeling to examine pull patterns in humans. His results on humans agreed with those on the turtles, that the conventional S-Pull is the most efficient pull, while a straighter I-Pull permits the swimmer to generate more power in freestyle swimming.

As this is a recent report, there has been no research to validate this theory under conditions of human performance. These new hypotheses into the power generated through the I-Pull need to be verified. As specified by the Ito model, an I-Pull will generate more power, as compared to an S-Pull. As Ito's theory is based on a computer model, testing needs to be done on the pull patterns of actual swimmers to see if there is indeed a significant difference in the power output between the I-Pull and the S-Pull.

Verification of Pull Patterns

The Ito study (2004) has opened up new research ideas that have not been previously considered. There are two main questions: (1) How can different freestyle stroke patterns be examined? and (2) How can arm power be measured most effectively? The I-Pull, being seen as generating more power, is a new concept and there is little, if any, information in the literature regarding this stroke pull pattern.

Progress in swimming is measured through the change in performance records. These records can be on various levels, from each individual's personal records, to school and meet records, to national and Olympic records. As a swimmer's times improve, it becomes progressively harder to go faster (i.e., it progressively takes more work to drop less time). In this quest to achieve maximum speed, minor changes in stroke technique and body position may result in the improvement desired by the swimmer. A drop of a few tenths or even hundredths of a second can mean the difference between a gold medal and no medal. Performance success can also lead to monetary rewards in terms of scholarships and endorsement money. Coaches and swimmers are constantly searching for techniques that will result in faster swimming. The swimming community needs empirical data to verify whether the I-Pull will produce more power and ultimately lead to faster swimming performances.

Need for Study

There have been no published studies to test how the power generated through the S-Pull compares with that through the I-Pull. For the past 40 years, stroke patterns have been analyzed primarily to assess how patterns vary by individual, not how one pull compares to another. Until the Ito (2004) study, the S-Pull had been thought as the best stroke pattern for all situations and no research was needed into a straight I-Pull. As stated previously, testing the differences between the two pulls has yet to be done. The results from a comparative study will help to either support the traditional S-Pull or provide more credence to the idea that the I-Pull generates more power and potentially greater swimming velocity.

All swimmers and coaches can potentially benefit from a comparative study. Before coaches and swimmers start using the I-Pull, they need to know that it works as a viable swimming technique. Coaches in any sport are keen to "jump on the bandwagon" when a new technique becomes known to a sport, especially if it is used by an athlete who is successful at a high level. However, new techniques need to be validated through scientific inquiry. The best athletes in a particular sport may be using a certain technique because it is biomechanically advantageous for their own bodies and not the population as a whole. Conversely, other swimmers may imitate a champion swimmer's technique that is biomechanically disadvantageous for their own bodies. Coaches need physical validation of Ito's computer model in order to have confidence in selecting the I-Pull as a training technique for their athletes.

The results of a comparative study may lead to situation specific training. If the results show that the I-Pull does indeed generate more power, coaches can begin to teach their swimmers to use this stroke in specific conditions. The original Ito report shows that the I-Pull generates more power while decreasing the efficiency of the stroke. Sprinters (50 meter and 100 meter competitors) could benefit most from the I-Pull as the emphasis in these events is power and speed. The sprint events last no-longer than a minute; these swimmers may afford a drop in efficiency for an increase in power that they may obtain through the proposed I-Pull. Swimmers in longer events (400 meter, 800 meter, and 1500 meter) may want to use the conventional S-Pull while utilizing the I-Pull at key moments – specifically at the end of a race when speed is important or when they need a quick burst of speed to pass an opponent or to prevent others from passing them.

Purpose of Research

The purpose of this study was to measure the differences, if any, in the power output generated from the conventional S-shaped pull versus a straight I-shaped pull during freestyle swimming in experienced swimmers. Participants learned each of the two pull patterns during a training period prior to data collection. The Power Rack was used to measure the amount of power generated through the use of both of the pull techniques.

Research Questions

Is there a significant difference in the power output in freestyle swimming as measured by the Power Rack in trained experienced swimmers using a straight I-Pull as compared to the traditional S-shaped pull?

Aside from power output, other variables were measured for differences:

- Are there differences in the amount of power generated in freestyle swimming with the two strokes between athletes who specialize in freestyle and those that specialize in one of the other three stroke disciplines (backstroke, butterfly, and breaststroke)?
- Is there a difference in the amount of power generated in freestyle swimming with the two strokes between athletes who specialize in sprint events (up to 100 meters) and those who specialize in non-sprint events (100 meters and greater)?
- Is there a correlation between power output and anthropometric measures of height, weight, and arm length?

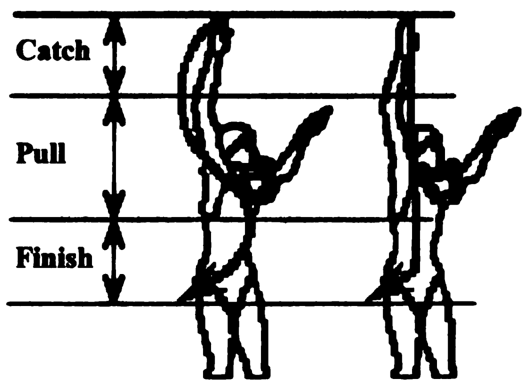
Assumptions

There were a few assumptions that were made to carry out the current study. One assumption was that the Power Rack was a viable device to measure power output in swimmers. The Power Rack is used on a regular basis by the majority of collegiate and elite programs to train and develop power, speed, and strength in the water. As it is a regularly used device, another assumption was that the Power Rack would not likely cause injury or hurt the participants in the study.

There were a few assumptions based on the video equipment and set-up of the underwater camera. There was only one underwater camera available for video analysis. It was assumed that the stroke patterns could best be analyzed from a perspective behind the swimmer when using a single underwater video camera. The other two possible camera positions, above or below the swimmer, would not have been easily implemented. The underwater camera consists of a telescoping lens that goes under the water, upon which the camera rests outside of the water. To take video underneath the swimmer would require a modification of the underwater camera to get this view. To get video above the swimmer would require an apparatus made so that the camera could look down upon a swimmer from above the pool. The above and below camera views would have required extensive modifications which would be beyond the scope of the current study.

Definitions

Catch – *Figure 1.* The initial part of the freestyle pull where the hand engages the water. In the S-Stroke the catch is the initial out-sweep of the hand away from the body. This can also be thought of as the top portion of the "S". In the I-Stroke the catch is the first part of the pull as the hand and forearm move from a horizontal to a vertical position in the water.



(a) S-Shaped pull (b) I-Shaped pull

Figure 1: A comparison of the S-Pull and the I-Pull (adapted from Ito, 2004)

Finish – *Figure 1.* The last part of the freestyle pull where the hand and forearm are at a position near the hip and initiate exit from the water.

Flume – A highly-technological swimming apparatus that is analogous to a treadmill for swimmers. A swimmer is able to swim against a controlled current flow of water created by the flume. The flume is used to monitor stroke behaviors and can be used for scientific research.

Freestyle – Includes any type of swimming that falls under competitive swimming. In other words, swimmers in a freestyle event can choose to swim any stroke variation they want as long as it remains legal. Most swimmers use the front crawl swimming stroke characterized by alternating right and left arm strokes and alternating right and left straight leg kicks.

I-shape pull (I-Stroke or I-Pull) – *Figure 1.* A freestyle swimming stroke pattern where the hand and forearm follow a straight line pull parallel to the midline of the body as they move underneath the body.

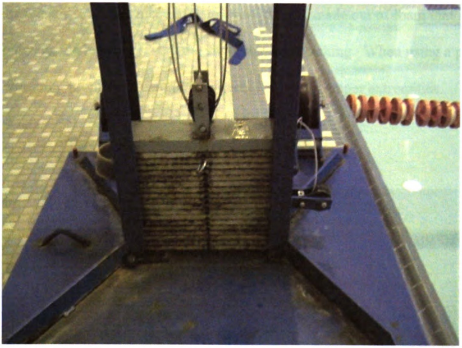
One-rep max – The largest amount of weight that can be lifted in a specific exercise by an individual at one time. This can be abbreviated as 1RM.

Power – Defined as the rate of work, measured in watts. In the current study it was defined as the amount of time it takes to move a set amount of weight a set distance on the Power Rack.

Power Rack – *Figure 2 and Figure 3.* A training device for swimmers consisting of a weight stack and pulley system. The Power Rack allows athletes to swim against a given resistance and develop in-water strength. The Power Rack is manufactured by Total Performance Inc. Mansfield, Ohio.

Figure 2: The Power Rack

(a)



(b)

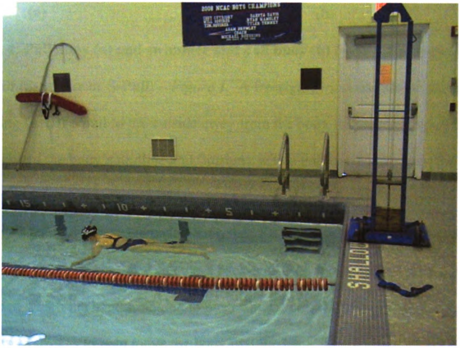


Figure 3: Power Rack detail (a), and swimmer using the Power Rack (b)

Pull buoy – *Figure 4.* A small piece of equipment usually made out of foam that is placed between the legs to prevent the swimmer from kicking. When using a pull buoy, swimming propulsion can only be generated by the upper extremities.

(a) **(b)**

Figure 4: Pull buoy (a) and swimmer and pull buoy (b) (www.isokineticsinc.com)

S-shape pull (S-Stroke or S-Pull) – *Figure 1.* A freestyle swimming stroke pattern consisting first of a pull to the outside away from the body followed by a pull back inside toward the body's midline and finishing with a pull back away from the midline

Scull – Short hand and arm movements that utilize lift forces to propel a person forward through the water. A scull is a sideways back-and-forth motion of the hand and forearm in which the hand is angled to push water backwards. It is used in competitive strokes to help move the body past the hand. The S-shape pull features a combination of sculls to move the body forward through the water.

Stroke length – A measure of how far a swimmer moves through the water in one stroke cycle. Stroke length is typically measured from the point where one hand enters the water until it enters the water again for the next stroke cycle. Stroke length can also be referred to as *distance per stroke (DPS.)*

Stroke rate – Frequency or number of strokes taken over a certain period of time.

VO2max – Can also be referred to as the aerobic capacity of a person. This is the maximum rate at which oxygen is consumed. VO2max measures the level of physical fitness in an individual. (Brooks, Fahey, White, & Baldwin, 2000)

CHAPTER 2 – REVIEW OF LITERATURE

Biomechanical Principles of Freestyle Stroke Technique

There are two general principles that can be applied to swimmers – Newton's Laws of Motion and Bernoulli's Lift Principle. Newton's Third Law of Motion states that for every action there is an equal and opposite reaction. Applying Newton's Third Law, a swimmer pushing water backwards results in forward propulsion of the body (Counsilman & Counsilman, 1994). This law holds true for all of the four stroke disciplines (backstroke, breaststroke, butterfly, and freestyle).

Initially swimmers were thought to pull their arms straight through the water much like a paddle to create a forward motion (Counsilman & Counsilman, 1994). Through the use of underwater cameras, Counsilman (1968) saw that swimmers actually moved their arms in a curvilinear S-shape. This S-shaped pull was attributed to the concept of Bernoulli's Lift Principle. Lift is a condition that is produced when a forward thrust of an object (blade, hand, or propeller) produces positive pressure on one side and negative pressure on the other. In a swimmer, the hand produces positive pressure on the palm surface and negative pressure on the top side of the hand. As the swimmer's hand moves through the water, the resulting force moves the swimmer forward. By moving the arm in an S-shape, the swimmer's hand acts like a propeller – it uses lift to produce a forward motion (Counsilman & Counsilman, 1994). Elite swimmers are able to grab the water so that the arm acts as an anchor and stays in one location in the forward-backward dimension. The hand stays in one place and the body moves past the hand. In non-elite swimmers, there is a degree of slippage that occurs; the hand exits the water behind the entry point. The S-Pull evolved so that the swimmer's pull would constantly encounter still water to move to produce these lift forces (Counsilman & Counsilman, 1994). The S-Pull allows a swimmer to move a relatively large amount of water a short distance which results in a more efficient pull; the I-Pull moves a small amount of water a relatively large distance (Counsilman & Counsilman, 1994). Since Counsilman's initial findings in 1964, the S-shaped curvilinear pull has been the accepted freestyle stroke pattern.

There are three parts to a swimming S-Pull as seen in Figure 1: catch, pull, and finish. In some swimmers, prior to the catch, there is a short glide period where the hand is moving forward relative to the water as it enters the water. This initial glide is dependent upon where the swimmer places the hand upon entry and varies from swimmer to swimmer. The catch starts with a short lateral scull away from the body followed by a scull back toward the midline of the body and is semi-circular in shape. As the arm travels through the pull section, the hand follows a natural pattern and starts moving backward and toward the lateral side of the body. The finish is denoted by elbow extension as the hand and forearm exit the water. The pull has also been divided into five parts: entry, down-sweep and in-sweep which together make the catch; out-sweep (pull); and up-sweep (finish) (Chatard, Collomp, Maglischo, & Maglischo, 1990).

The straight-pull, or I-Pull theory, is based on Ito's (2004) study. As stated earlier, his work was derived from studying turtles and was extended to include a computer model of human swimming. The I-Pull is devoid of the lateral back-and-forth sculling patterns found in the S-Pull; instead, the hand follows a straight back pull. A video analysis taken from behind the swimmer will show that in the S-Pull the hand and arm will engage in a significant amount of lateral movement while in the I-Pull there is little or no lateral movement. Figure 1 shows a comparison between the different pull-patterns of these two strokes. Beside the path that the hand travels through the water, the major difference between the two pulls is the position of the elbow during the catch. In the S-Pull the elbow is extended during the catch while in the I-Pull the elbow is flexed as soon as the hand enters the water (Ito, 2004). In both techniques, through the pull and the finish, the elbow has similar positioning.

The pull-pattern for swimmers is a three-dimensional movement and involves rotation of the body as well. A swimmer's body does not stay flat in the water when swimming the front crawl stroke but rather it rotates along an axis running from the head to the feet. The frame of reference is important when describing the pull pattern. Is the arm and hand moving relative to the body of the swimmer or another reference point, such as a fixed point in the pool? The frame of reference can affect how the pull pattern is described. In the case where the body serves as the frame of reference body rotation is an important factor. The S-Pull can be described as when the body has maximum rotation and the arm and hand are set in a fixed point in the water; as the body rotates, the arm and hand make an S-shape relative to the body. Conversely, the I-Pull will have minimal body rotation with the arm and hand not contained in a fixed point in the water.

Using a fixed point either behind or below the swimmer as a reference point results in a different description of the two pull styles. In this case, body rotation is not a factor in the description of the pull pattern. The visual description of the stroke will only take into consideration the arm and hand as they move relative to the reference point. The S-Pull will have lateral movements with elbow flexion, whereas, the I-Pull will have a straighter arm with few, if any lateral. When a fixed point in the pool is used as the reference point, the swimmer's body can rotate as much or as little as possible with either stroke technique as the focus and description of the stroke is solely with the arm and hand.

There are few studies that have closely looked at stroke patterns. One reason for this is that since Counsilman's findings, the S-type pull has been accepted as the biomechanically superior stroke technique. A second reason is that pull patterns are three-dimensional and in-depth analysis takes a lot of time and equipment which is not available to a lot of researchers. Ito and Counsilman agree that the S-Pull is the more efficient pull. Chatard et al. (1990) measured swimming performance based on VO2max, stroke pattern, lift forces on the arm, and anthropometric measures in nine male competitive swimmers. Participants in this study were labeled either "skilled" or "unskilled" based on actual performance compared to theoretical performance. The "skilled" swimmers performed better then predicted and had distinct differences in their stroke pattern than the "unskilled" swimmers; namely, the skilled swimmers had a shorter catch phase and a longer finish phase to their strokes. There was a strong correlation ($r = 0.77$) between stroke depth and the generation of lift forces.

Swimming Power

Power, by definition, is the rate of work done. Mathematically, power can be represented as:

$$P = W/t = F*d/t$$

Where: P = power
W = work
F = force
d = distance
t = time

Equation 1: Power calculation

Power can be applied to athletes and can be thought of as the rate at which a muscle produces a force. Athletes who are able to produce the most power are going to be producing the most force at the fastest rates.

Swimming is known as a full-body sport. Swimmers are constantly activating muscles throughout the body as they move through the water. In propelling the body, the lower body employs the kick; the upper body and arms contribute to the majority of the forward velocity; and the mid-section, or core, links the upper and lower bodies together while helping to maintain a straight-line body position. The muscles of the shoulders, upper-back, and triceps are the muscle groups that are the most important in providing swimming speed. These are the muscle groups that hypertrophy the most through in-water training and are targeted via strength training out of the water. Swimming power is going to be affected by the strength of these muscles. Swimming-specific training, including power, can be classified into two categories: out-of-the-water based training, or "dryland" training and water-based training.

Dryland measures of power

Arm power for swimmers has been typically measured out-of-the water in three different ways: swim bench, cycle ergometry, and resistance exercises. All three of these methods have benefits and drawbacks when it comes to analyzing power in swimmers. Cycle ergometry and resistance exercises are common methodologies and both are easy to use; the swim bench is a common swimming training device used by many universities and club teams. The main drawback to all three methods is the question of how well do the dryland measures transfer to actual swimming power.

Swim bench

The swim bench (H and M Engineering, Gwent, Wales) (Figure 5) is a dryland device that has been used in numerous studies (e.g., Costill, King, Thomas, & Hargreaves, 1985; Johnson, Sharp, & Hedrick, 1993; Neufer, Costill, Fielding, Flynn, & Kirwan, 1987; Sharp, Troup, & Costill, 1982; Swaine, 1997, 2000; Tanaka, Costill, Thomas, Fink, & Widrick, 1993) to measure arm power. The bench is constructed so that the participant can lie prone on it. The bench has a hand paddle and pulley system that allows for simulated swimming motion outside of the water. Transducers can be used with the swim bench to measure power output (Swaine, 1997).

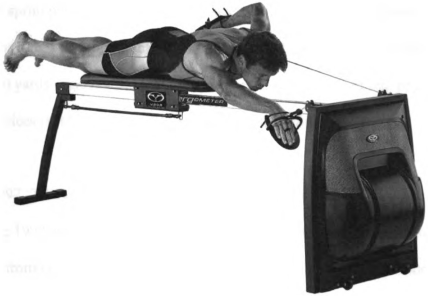


Figure 5: A swim bench (http://www.swimshop.pl)

Sharp, Troup, and Costill (1982) tested 22 male and 18 female teenage swimmers to correlate upper body power and sprint freestyle performance. Maximum arm power, peak force, and work were all measured on a swim bench. The bench has resistance settings that provide "a constant amount of acceleration in proportion to the force applied by the user." There were three data collection components employed in this research: (a) participants performed 25-yard sprints in the pool, (b) the swim bench was used to measure power, and (c) fatigue. Peak power and fatigue were measured on the participants while they performed a 45-second interval on the swim bench. The power generated by the swimmer on the bench was measured by dividing time (the 45-second interval) into work output from the swim bench through Equation 1. Participants were tested twice on the bench to establish reliability of the apparatus. The results gave a significant positive correlation (r = 0.90) between arm power (measured on the swim bench) and sprint performance. As the distance swum increases, the amount of power generated becomes less important. Power is still significant, however, in distances as great as 500 yards. The investigators suggest that measurements of arm power should be made in devices that best imitate the actual swimming motion.

Swaine (1997, 2000) has conducted two studies utilizing the swim bench to measure arm power. The 1997 study focused on the arm power generated by swimmers who were recovering from injury. The 2000 study added a leg-kicking ergometer to the swim bench that was able to isolate arm and leg power. Three studies (Sharp et al., 1982; Swaine, 1997, 2000) agree with previous results (Olbrecht & Clarys, 1983) that, while the swim bench is good for measuring arm power, it is not suitable for imitating the swimming motions themselves. Motion in water is much different than that on land due to the buoyant nature of water. Even though the bench can be used to supplement training, it should not be used as a replacement for swimming.

Cycle ergometry

Cycle ergometry and resistance exercises have also been used to measure arm power. A cycle ergometer relies upon a single wheel in which the resistance can be adjusted to measure work and power output. There are two different types of cycle ergometers: one for measuring leg power and one for measuring arm power. Hawley, Williams, Vickovic, and Handcock (1992) used arm and leg cycle ergometry to measure power. Twelve male and ten female teenagers performed a Wingate Aerobic Test for both the upper and lower body to measure maximum power output. Participants also completed timed swims of 50

2

m and 400 m. Their results had a correlation of 0.63 between sprint speed and arm power. These results suggest that there may be better methods than cycle ergometry to assess potential swim performance. The Wingate test was the only measure that predicted sprint performance uniformly across genders. The results of this study showed that arm power significantly contributes (r = 0.70) to performance in distances up to 400 meters.

Resistance exercises

Resistance exercises can include any type of strength exercises such as the bench press or the squat lift. Johnson, Sharp, and Hedrick (1993) used a 1RM on a bench press on a Universal machine and compared these results to swimming speed and power. Simmons (2003) used 1RM bench press, medicine ball exercises, and vertical jump to compare male and females and how these exercises correlate to swimming performance. Tanaka et al. (1993) used an 8-week resistance program that focused on developing swimming-specific muscles. The exercises used in this study included chin-ups, dips, lat pull-downs, elbow extensions, and bent-arm flys. These three studies all agree that there is little correlation between resistance strength and swimming velocity and that other methods of strength training are superior for swimmers.

Swimming specific measures of power

Swimming power can also be measured directly through water-based devices. These devices include the Measurement of Active Drag system (MAD-system), swimming flume, videography, Power Rack, and Swimgate Test.

Measurement of Active Drag system

Hollander et al. (1986) have developed the MAD-system. This system (Figure 6) consists of a series of hand-pads below the water that the participant is able to push off while swimming. The system is connected to transducers that allow for power measurements. Toussaint has led a group that has used the MAD-system in a series of studies (1988, 1990a, 1990b, 1990c, 2002) as a means of measuring swimming efficiency and power. The MAD-system is unique to this research group.

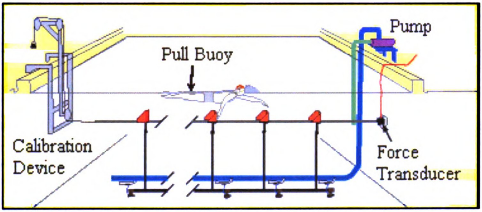


Figure 6: The MAD-system (adapted from Toussaint, 2002)

Toussaint, Knops, de Groot, and Hollander (1990) published a study that measured arm power via the MAD-system. Transducers in the MAD-system enable force and drag measurements to be made. The study was done on 10 competitive swimmers ages 19-24 years. A pull buoy (Figure 4) was used during the study to minimize leg effects. Respiratory (efficiency) measures were also taken to find the ratio of power output to power input. The efficiency of the participants ranged from 5.1 to 9.5% which was in agreement with Bobbert's (1960) and Davies & Sargeant's (1974) published studies of arm cranking (as cited in Toussaint et al., 1990). Berger, Hollander, and de Groot (1997) measured technique and related power losses of front crawl swimming. The participants in their study were seven males and four females who were at the national or international level in swimming or triathlons. The swimmers performed two 400 meter swims at different velocities – one with the MAD-system and one without it. Underwater videography was used to measure the orientation of the hand and arms during the pull phase of the stroke. The study concluded that different phases of the stroke have different proportions of lift and drag. The drag force is opposite the line of motion of the hand and thus there cannot be lift (propulsive) forces without the drag force. The role of power was found to overcome drag and provide propulsion.

Swimming flume

Another water-based research device is the swimming flume. The flume is an advanced piece of technology, a few of which exist in the world. In the flume, a swimmer swims in one place against a water current controlled by the flume that can be changed; the flume can be thought of as a swimming treadmill. Aside from a variable current, researchers can easily accommodate oxygen uptake (including VO2max) equipment, and the flume provides viewing windows for biomechanical and video analysis. The flume is also built in a hyperbaric chamber so that training at different altitudes can be simulated.

Toussaint, Wakayoshi, Hollander, and Ogita (1998) used a modeling technique along with the flume to measure aerobic and anaerobic capacity related to swimming performance. The force (F_d) to overcome drag (Equation 2) is related to the square of velocity (v) while the power (P_d) to overcome drag (Equation 3) is related to the cube of velocity. In these two equations, *A* is a proportionality constant based on water density, drag coefficient, and cross sectional area of the swimmer's body.

$$F_d = Av^2,$$

where: F_d = force to overcome drag

A = proportionality constant

v = velocity.

Equation 2: Force to overcome drag

$$P_d = Av^2 * v = Av^3,$$

where: P_d = power to overcome drag

A = proportionality constant

v = velocity.

Equation 3: Power to overcome drag

Using Newton's third law of motion, propulsion in swimming is obtained by pushing (pulling) water backward. The total power (Equation 4) is the sum of the power to overcome drag (P_d) and the power to move a given mass of water (P_k).

$$P_o = P_d + P_k,$$

Where: P_o = total power

P_d = power to overcome drag

P_k = power to move a given mass of water

Equation 4: Total power

The investigators tested eight college-age male swimmers in a swimming flume. Measures of VO2max and anaerobic power were used to create a computational model to predict swimming performance at various distances. Aerobic capacity better predicts performance at longer distances rather then shorter distances. The proposed model in the study, putting an emphasis on anaerobic power capacity, poorly predicted aerobic performance.

Videography

Berger et al. (1997) used videography to measure the motion of arms through the water. Anatomical landmarks were identified to measure arm movement and body velocity. The swimmers swam a 400 meter distance twice – one swimming normal and one with the MAD-system. The videography was used to identify different phases of the swimming pull. In this study, the researchers used a pull buoy to support the legs, isolate the arms, and to eliminate any leg effects. Similar studies (Toussaint, 1990a & 1990b) in the literature have focused solely on arm power used a pull buoy as well.

Power Rack and Swimgate test

Another swimming-based device is the Power Rack (Figure 2). The Power Rack is a weight and pulley system that allows a swimmer to swim against a known amount of resistance. The swimmer wears a belt that is then attached to the Power Rack. The swimmer then sprints approximately 10.1 meters until the weight stack hits the top of the rack. The Power Rack is a common training device that is found in a majority of collegiate and elite swimming programs. Power (P) is a product of force (F) and velocity (v):

$$P = F*v = mg*\Delta x/\Delta t,$$

Where: m = mass

g = acceleration due to gravity

Δx = amount of displacement

Δt = time

Equation 5: Power calculation for the Power Rack

When using the Power Rack, a given mass, m, is moved a given distance, Δx, in a given amount of time, Δt. Using the acceleration due to gravity, g, the power can easily be calculated.

There have been very few studies that have used the Power Rack as a means of measuring power output. Johnson et al. (1993) measured power through both the Power Rack and swim bench. They also looked at individual strength through a 1RM maximum bench press on a Universal gym. Simmons (2003) measured power through the Power

Rack and a Swimgate Test. She examined differences between genders and body types on the power generated during swimming. The Swimgate Test is comparable to the Wingate Test as a measure of power. In the Swimgate Test a swimmer performs a 30-second all-out swim while attached to a tether (Stager & Tanner, 2004).

There is a lack of published information utilizing the Power Rack as a measurement device. The Power Rack is a common training apparatus utilized by a majority of competitive and elite swim teams. It is a simple device that can easily be used for scientific measures. As there are few facilities that have the advanced technology (swimming flume and MAD-System) to assess swimming performance, it is surprising that the Power Rack has not been used in more studies. By using the Power Rack as a measurement device, a comparative research question to be explored relates to the validity of the Power Rack as a research device in swimming.

Limitations of Potential Equipment

There are some limitations in terms of the various equipment and methods discussed. The MAD-system and swimming flume are expensive pieces of technology that are not available to most researchers. The MAD-system also presents a limitation in its inherent design. There are pads attached to poles in which a swimmer uses to push against as he/she swims across the pool. The current study examines the shape of stroke pull patterns. By having these pads, the MAD-system cannot take into account the sculling motions and forces a swimmer to pull such that the hand and forearm do not change pitch nor does the hand change positions in the horizontal or vertical dimensions. . In reality, the hand, forearm, and arm are moving in three dimensions underwater. In addition, there is no swim bench available to this researcher for power measurements. The availability of a Power Rack and an underwater camera served as a basis of the instrumentation for this study.

Swimming Velocity, Stroke Rate, and Stroke Length

Swimming velocity (V) is directly affected by stroke rate (SR) and stroke length (SL) by the following equation:

$$V = SR \times SL.$$

Equation 6: Swimming velocity, stroke rate, and stroke length

A number of studies (Chatard et al., 1990; Craig & Pendergast, 1979; Craig, Skehan, Pawelczyk, & Boomer, 1985; Tanaka et al., 1993; Toussaint, 1990; Wakayoshi et al., 1993, 1995) have all examined relationships between swimming velocity, stroke rate, and stroke length. There is a general agreement in these studies that in higher skilled swimmers, an increase in velocity is more attributed to an increase in stroke length rather then stroke rate. Craig and Pendergast's (1979) study had the largest number of participants (41 males, 22 females) and plotted velocity versus stroke rate for each participant. While this was an early study, it did show that the fastest swimmers had the greatest distance per stroke (DPS) at sub maximal velocities. Additionally, there was a correlation ($r = .52$) between maximum DPS and maximum velocity. Wakayoshi et al. (1995) performed measurements on ten males swimming in a flume set at varying flow rates. Their work suggests that high performance (i.e., fast) swimmers have a lower SR with an i

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with an increased SL and that SR correlates more closely with the square of the velocity than with velocity. Swimmers who take fewer strokes at a given velocity are metabolically more efficient and more technically sound. A second study by Wakayoshi et al. (1993) showed that after six months of training, increases in velocity were attributed more to an increase in stroke length than stroke rate. Chatard et al. (1990), on the other hand, found a closer relation between stroke rate and velocity. His work compared a group of unskilled swimmers with skilled swimmers. The skilled swimmers had a higher stroke rate with a lower stroke length. Additionally, Chatard found that stroke length and anthropometric arm measures were not significantly related.

Implications of the Literature on the Current Study

Power output in swimmers has been extensively studied. The impact of stroke patterns and the use of the Power Rack as a research tool, however, have been minimally studied. In addition to the main goals of the research, a concomitant intent of the current study was to shed light on the validity of the use of the Power Rack as a research tool and to provide more data on stroke patterns. The literature also provides for some recommended resistance values when using the Power Rack. The study by Simmons (2003) illustrated how to conduct and establish criteria for a 1RM test on the Power Rack.

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CHAPTER 3 – METHODS

Research Design

The research design for this study involved participants serving as their own controls. Prior to the study, participants were provided with an informed consent form (Appendix A) to read and to learn about the current study and to sign if they were interested in participating. Subsequently, those consenting to participate completed a swimming background questionnaire (Appendix B) to provide some characteristic data about themselves and their swimming ability. Participants were randomly assigned to one of two groups. Both groups performed a pretest during the first week of the study to establish a 1RM on the Power Rack and then participated in the 4-week intervention period in which they were instructed on the two different stroke styles. After the intervention, one group (Group 1) was tested first with the I-Pull and second with the S-Pull; the second group (Group 2) was tested first with the S-Pull and then with the I-Pull. Table 1 has the overview of the research design.

<table>
<tr><td rowspan="4">Participants randomly assigned to Group 1 or Group 2</td><td colspan="4">Group 1</td></tr>
<tr><td>1RM Pretest on Power Rack</td><td>Intervention: Teach the I-Pull and S-Pull for 4 Weeks</td><td>Test I-Pull</td><td>Test S-Pull</td></tr>
<tr><td colspan="4">Group 2</td></tr>
<tr><td>1RM Pretest on Power Rack</td><td>Intervention: Teach the I-Pull and S-Pull for 4 Weeks</td><td>Test S-Pull</td><td>Test I-Pull</td></tr>
</table>

Table 1: Research design

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Threats to Validity

Internal validity

The three biggest threats to internal validity were: reactivity to testing, expectancy effects, and on-stage effects. Reactivity is how the participants respond to the testing. In this research design, there was a test before the intervention to establish the amount of resistance on the Power Rack for the future tests. The intervention was not used to measure the amount of change from the pretest, but to teach and compare the two stoke techniques. Expectancy effects were of concern to the researcher. Participants may feel the need to give a higher effort on one stroke style then on the other. Participants were told to give all-out efforts on each trial to minimize this threat. Additionally, participants were not informed about the possible outcomes so they would not subconsciously try harder with one stroke versus the other. The last threat to validity, the on-stage effect, would be minimal since the Power Rack is a training tool that the participants had used throughout the season on a regular basis. Swimmers are constantly being evaluated by time-performance whether in practice or during competition. It was not likely that the participants would feel as if they were performing for someone; they were just doing something they normally did during training.

External validity

The external threats to validity were minimized and not a major concern for this study. Randomization put the participants into different groups and they served as their own controls. The Power Rack has been identified as a device that can measure swimming power whi

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power while duplicating the natural swimming motions; this minimized the threat to experimental arrangement. The interaction of testing and treatment was minimized by the design of the study.

Selection criteria

The participants for this study were fourteen college swimmers and one high school swimmer. The college swimmers were team members on a local college team while the high school swimmer was a member of a local high school and club team. The swimmers were at a skill level where they have control and mastery of their strokes and could make subtle changes to their technique. This population was considered as "experienced swimmers" and required a minimal amount of teaching to learn and master the I-Stroke technique. All members participated in daily swimming and conditioning exercises. The recruitment of participants for the study was not limited to those swimmers whose main stroke was freestyle; swimmers of all stroke disciplines were recruited for the study. Participants were healthy and free from injuries and orthopedic problems in the upper extremities. Additionally all participants were required to provide informed consent (Appendix A) to participate in the research.

Recruitment

The college swimmers were all part of the varsity swim team at a local institution of higher learning. In addition, the lone high school swimmer was on the local club team. All participants had the choice whether or not to participate in the study.

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Informed Consent

Each participant gave signed informed consent prior to becoming involved in the study. As all participants were 18 years of age or older, there was no need for parental consent. Prior to participating in the research project, the secondary investigator held an informational meeting. This meeting presented the potential participants with an overview of the research and they had the opportunity to ask any questions regarding the research.

Swimming Background Questionnaire

Prior to testing, each participant submitted a completed swimming background questionnaire, which can be found in Appendix B. This questionnaire detailed the swimming experience of the participant in terms of years in the sport, stroke discipline, distance specialty, distance of daily practice, number of practices per week, and how he/she characterized his/her freestyle pull pattern. The questionnaire also asked for the participants to provide some basic background information for the research. The questionnaire was used to describe the population tested.

Intervention

The intervention lasted four weeks. For five days a week, the participants swam a practice that lasted from 1 to 1.5 hours in which the athletes swam between 3000 and 4500 meters. Every practice had part of it devoted to the learning and execution of the two stroke techniques. This lasted anywhere from 15 to 30 minutes of the workout.

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During the first week of the intervention, the participants concentrated on learning the two stroke techniques. The participants were instructed to visualize how the arm and hand move relative to the body. The technique of the S-Stroke involved focusing on shifting the pitch of the hand and arm in the vertical direction. The swimmers worked on a semi-circular catch at the beginning of each S-Stroke. In addition, sculling drills were performed to reinforce the change in direction of the hand and arm. The practice of the technique of the I-Stroke directed the participant to concentrate on keeping the hand and arm in the same orientation for the duration of the pull. The participants were instructed to always face the palm and forearm opposite the direction of travel and there should be no lateral sculling motions. To help the swimmers concentrate on pulling in one direction, they were instructed to have their hands follow the outside of the black line that is on the bottom of the pool in each lane.

Swimming speed was incorporated into the training during the second week of the intervention. The participants swam short sprints of 10 meters with each stroke technique. Before these sprints, the two stroke styles were reinforced with the drills that were introduced during the first week. As the intervention progressed into the third and fourth weeks, the amount of drilling and technique work decreased. The participants increased the amount of swimming they did with each stroke style. In addition, the amount of sprinting, in terms of distance and number of repeats, increased during the second two weeks. Appendix C has additional information on drills and practice sets that were used for the two stroke styles.

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For example, during the first week of the intervention, the participants swam a set of 20 swims of 22.8 meters. These were swum so that the first 10 were a drill incorporating the stroke technique and the second ten were swum using the specific stroke technique. During the second week, this set progressed into five sets of four swims of 22.8 meters each. A set of four had the first two being a drill, the third being a swim, and the fourth being a swim at top speed. In the third week this set evolved into ten sets of two where the first was a drill and the second was a swim at top speed with the proper stroke technique. In the fourth week, all swims of the set were done with the proper stroke style and at top speed.

One-Rep Max Test on Power Rack

During the first week of the intervention, the participants performed Power Rack trials to find their 1RM that would establish resistance levels for the final test. The first trial began with 4.5 kg of resistance and the weight was increased by 2.3 kg each trial. A 1RM was reached when a trial was 3 seconds (or more) slower then the first trial. This followed the criteria set forth by Simmons (2003). Simmons also included a condition for establishing 1RM with stroke count as well as time. Stroke count was included in the 1RM testing but resulted in a wide variable range of results and would have resulted in an early termination of the test. Due to this large variability with each participant, time was favored over stroke count when determining the 1RM. Participants used a pull buoy between their legs and a strap binding the ankles to minimize the effect of legs on the results. In addition, the participants began each trial without a push-off of the wall. The participants were prone in the water with their feet just off of the wall and thus began each trial

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each trial from a stationary start. Participants were instructed to swim each trial at top speed and as fast as possible. The timing of a trial started at the initiation of the first arm stroke and stopped when the weight stack reached the top of the Power Rack. Participants rested one minute between trials and repeated until a 1RM was reached.

The 1RM testing led to some changes in the proposed procedure. Initially the protocol was to have the participants perform the final testing at resistance levels of 25, 50, and 75% of the 1RM. The Power Rack only allowed for a minimum of 4.5 kg of resistance with added increments of 2.3 kg. Since the participants did not use a push-off of the wall, this greatly reduced the amount of weight that they could pull. Under normal training conditions the athletes start with a push-off of the wall. This push-off engages the legs and produces momentum which helps the swimmers get up to top speed quickly. As this study is concerned with arm power, the legs were not used and this affected the testing conditions. Calculation of the three resistance levels (25, 50, and 75% of 1RM) did not equal a weight that was available for use on the Power Rack. For example, Male6 had a 1RM of 11.3 kg which corresponds to resistance levels of 2.8, 5.7, and 8.5 kg for 25, 50, and 75% of 1RM, respectively. These were adjusted to 4.5, 6.8, and 9.1 kg for the final test. All adjustments were made to the resistances closest to the 25, 50, and 75% permissible on the Power Rack. These adjustments were made throughout the testing. For the final testing, each participant did three trials on three different resistance levels; they were not, however, at the 25, 50, and 75% of the 1RM levels as initially proposed. Subsequently, the resistance levels were termed Level 1 (lowest weight), Level 2 (middle weight), and Level 3 (highest weight).

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Data Collection Procedures

All testing took place at a local competitive swimming pool. The final data collection was done at the end of week four of the intervention. On the day of testing, participants arrived at the pool with their swimsuit and goggles. Additionally, participants were expected to be well fed and rested for testing. Participants were initially measured for weight, and upper extremity length. Weight was measured with a standard scale to the nearest pound. The upper extremity was measured as one length from the acromion process to the dactylion (tip of the middle finger) with a tape measure to the nearest inch. Participants provided their height to the nearest inch. All measures were converted to metric units for calculation purposes. Appendix D contains data sheets that were used for anthropometrical and power measures.

Resistance Level	S-Pull	I-Pull
Level 1	9 Randomized Trials: 3 at Each Level	9 Randomized Trials: 3 at Each Level
Level 2		
Level 3		

Table 2: Power Rack testing matrix

Prior to testing, the participants swam a warm-up of 600 meters that consisted of swimming, kicking, and pulling. After the warm-up, they swam eight sprints of 10 meters, fou

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meters, four with each stroke technique. Each participant performed 18 swims on the Power Rack – nine trials using the S-Pull and nine trials using the I-Pull. The nine trials by stroke were further divided into three different resistance levels as seen in Table 2. Each group of nine trials was randomized by resistance and participants were not aware of the resistance level of each trial until they physically experienced the resistance during the trial. During these trials, the participants used a pull buoy between their legs along with a strap binding their ankles to minimize the kicking affects. Before each trial, verbal instruction was given to reinforce the proper stroke style and to ensure an all-out effort. Examples of the cues used were:

> "Use a big S-Pull during each stroke; think 'out-in-out' "
>
> "Straight pull, keep the hand and arm moving backward, trace the black line"
>
> "All-out effort here, no holding back"

During testing, participants were instructed to swim each trail without breathing to eliminate the influence of taking a breath on the technique.

The testing was done in the same way as the 1RM testing in that the participants began prone in the water with the feet just at the wall and did not push-off the wall to start a trial; again, this was to eliminate leg effects from the study. The participants were instructed to swim each trial as fast as they could. Timing started with the first arm stroke and stopped when the weight stack reached the top of the Power Rack. Participants took approximately one minute of rest between Power Rack trials. After the first nine trials of one stroke style, participants took ten minutes of active rest. Active rest in this study was defined as any combination of easy swimming and rest. The design of the rese

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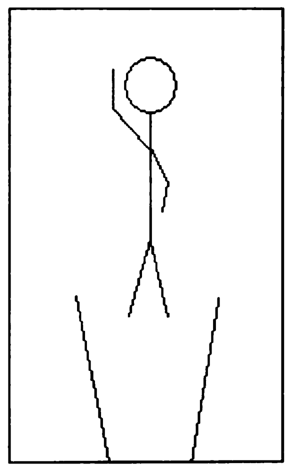
of the research was a counterbalanced study; one group performed the nine random trials with the I-Pull first, took an active rest, and then performed the nine random trials with the S-Pull; the second group performed the S-Pull first and then the I-Pull second. Testing was done on an individual basis and the testing sessions each lasted 30-45 minutes.



Camera

Figure 7: Schematic of camera position – aerial view of underwater camera and swimmer

Each trial was videotaped using an underwater camera. The underwater camera set-up consists of handheld camcorder and the underwater camera attachment. The camcorder model used was the Sony Handycam DCR-DVD305. The camcorder has 1.07 megapixels with an effective resolution of 0.69 megapixels. The camcorder recorded directly to a DVD. The underwater camera attachment came from the Underwater Camera Company of America. The underwater camera consisted of a telescoping pole upon which the camcorder attached. The camcorder was attached via video cables to the pole, which then extended down into the water. Due to the set-up, the zoom capabilities of the camera were disabled. The camera was positioned (Figure 7) on the wall and capture

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captured rear-views of the swimmers as they swam away from the wall. The video was used to determine and verify compliance with assigned stroke styles.

As previously described, the Power Rack consisted of a weight stack and pulley system. The Power Rack has an adjustable Velcro belt that attaches the swimmer to the cable and weight stack. The length of the cable allows for a swim of 10.1 meters. The weight stack is adjustable from 2.27 to 45.4 kg (5 to 100 lb) in 2.27 kg (5 lb) increments. Equation 5 was used to calculate power in units of Nm/s. The power calculations were averaged across each of the three trials at each level of resistance for each of the two stroke styles. In terms of psychometric properties, the Power Rack has already been identified as a valid and reliable research and training apparatus (Johnson, 1993; Simmons, 2003).

Aside from the variables of time and resistance for calculating power, the setup of the Power Rack created other variables involving the length of the wire and the angles created with the pool and the water. Figure 8 has a schematic representation of the Power Rack setup for this study. The Power Rack stood on the pool deck 32 cm above the surface of the water. The lengths and angles were dependent on how far a swimmer has progressed (l in Figure 8) during a trial. The maximum length of wire that can be extended from the Power Rack is 1005.8 cm; based on the experimental setup in Figure 8 the maximum distance a swimmer could travel was 1005.3 cm. The relationships between l, w, α, and β can be found in Table 3 ranging from $l = 30$ cm (standing in water next to the pool wall) to $l = 1005.3$ (maximum length swum in the pool).

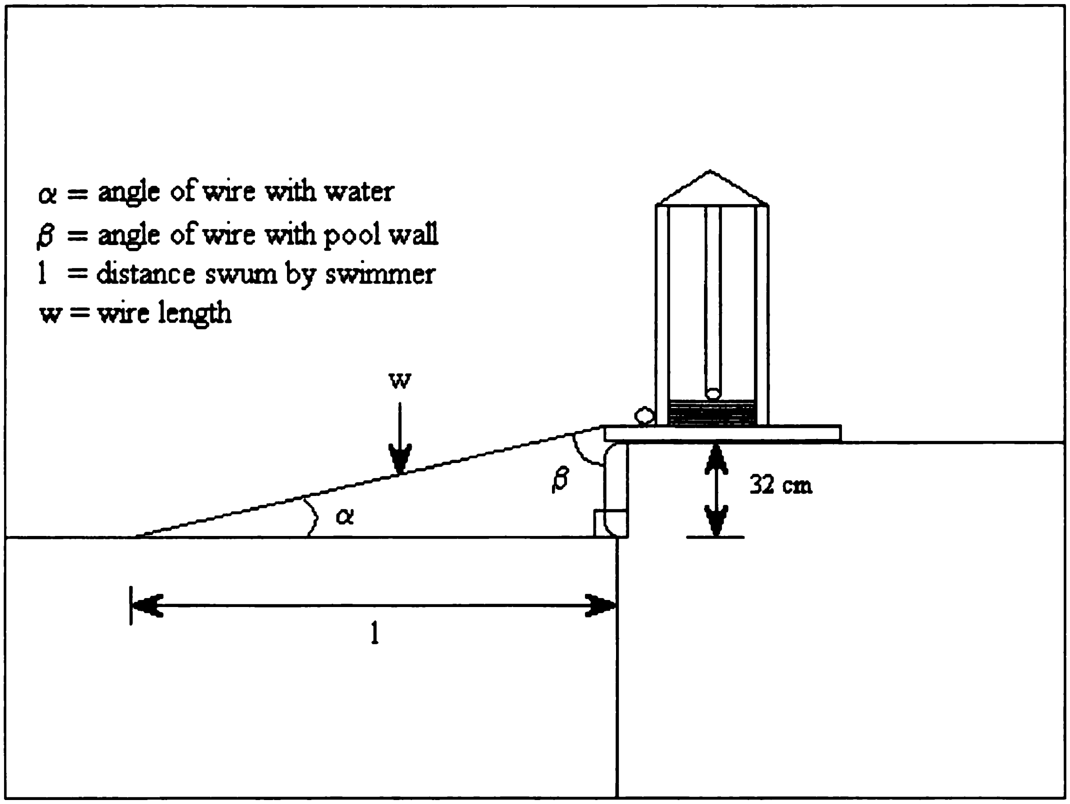

Figure 8: Power Rack schematic (not to scale)

l (cm)	w (cm)	α	β
30	43.9	46.8	43.2
50	59.4	32.6	57.4
100	105.0	17.7	72.3
150	153.4	12.0	78.0
200	202.5	9.1	80.9
250	252.0	7.3	82.7
300	301.7	6.1	83.9
350	351.5	5.2	84.8
400	401.3	4.6	85.4
450	451.1	4.1	85.9
500	501.0	3.7	86.3
550	550.9	3.3	86.7
600	600.9	3.1	86.9
650	650.8	2.8	87.2
700	700.7	2.6	87.4
750	750.7	2.4	87.6
800	800.6	2.3	87.7
850	850.6	2.2	87.8
900	900.6	2.0	88.0
950	950.5	1.9	88.1
1000	1000.5	1.8	88.2
1005.3	1005.8	1.8	88.2

Table 3: Relationships between lengths and angles of Power Rack setup

(a) $\alpha = sin^{-1}\ l/w$ **(b)** $\beta = cos^{-1}\ l/w$

where: α and β = the angles in Figure 8
l = distance from the wall
w = length of the wire pulled on the Power Rack

Equation 7: Calculations of length and angle parameters for the Power Rack

Freestyle Pull Technique

Freestyle pull technique was analyzed by taking underwater video of each participant to classify the stroke patterns. The underwater camera was positioned on the wall where the participant began each trial. The camera recorded perpendicular to the wall as the participan

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participant swam away, providing a rear view of the swimmer. This rear view was used to analyze which stroke pattern was used by each participant for each trial. For stroke verification the video record of each trial was viewed again at a later date and the stroke pattern used was then described. The described stroke pattern was then compared to the prescribed stroke pattern for a possible match. The difference between the strokes is that the S-Pull features lateral sculls, while an I-Pull has minimal lateral-medial movements of the arm and hand. The biomechanical characteristics of each swimmer were described as well during the stroke analysis.

Testing Personnel and Qualifications

The investigator responsible for research in this study led and oversaw all aspects of testing. This researcher has an extensive background in swimming both as an athlete and as a coach. He was a competitive swimmer for 12 years, is an American Swim Coaches Association Level 2 certified coach, and currently coaches at the collegiate level. He recruited the participants, provided background information on the study, and conducted the intervention and instruction for the stroke technique. There were four additional personnel that assisted during the testing sessions. These four people were other coaches and swimmers. Three of these individuals served as timers and each trial had these three times recorded for the power calculations, which were later averaged for power output. One timer served also as the recorder to write down the three times for each Power Rack trial. The second timer had the added task of adjusting the resistance of the Power Rack before each trail to match the requirements of randomization. The fourth person was needed to operate the video camera and to count the number of strokes that were taken by each pa

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each participant during each trial. Stroke counts were measured by counting the first stroke and ended with the last full stroke; any partial strokes at the end of a trial were not included as measurements. Testing personnel knew how to appropriately use a stopwatch and/or were able to use the underwater camera system. These were all simple tasks that required a minimal amount of training, if any. Video analysis of stroke patterns was done by the secondary investigator. The stroke patterns were viewed at a date later then the trials. The secondary investigator viewed the trials, made comments, and described the stroke pattern used. These were then compared to the stroke style that was used for verification purposes. As there was a gap of time between the testing and the video analysis, the secondary investigator did not have prior knowledge of which stroke style was used for each trial and independently described the characteristics of each trial.

Data Management

The secondary investigator had primary access to data and was responsible for security and storage of the data. The secondary investigator's advisory committee also had access to the research data. The data included testing measures – anthropometrical measures, Power Rack trial data, all videography of the participants, and identification of participants to their testing aliases. Informed consent forms and the swimming background questionnaire were also included among these secure items. After testing was completed and the data was analyzed, individual participants had the option to review their results.

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Data Analyses

Descriptive statistics were completed on data gathered from the swimming background questionnaire, anthropometric measures, and the Power Rack. The means and standard deviations of power at each resistance level for each pull pattern were calculated using the average of the three times measured by the timers. In addition the means and standard deviations were calculated for age, height, weight, arm length, years spent swimming, and the length of their recent workouts. The participants were also classified in terms of their stroke and distance specialties.

In this experimental design, each participant acted as his/her own control. The main research question was to determine if there was a difference between the power generated by the two stroke techniques. A t-test ($p < 0.05$) was used to test for significant differences in power between the two different pulls. The dependent t-test was used to compare the I-Stroke and S-Stroke while the independent t-test was used to compare different populations. The t-test was calculated at each level (low, middle, high) of resistance. Aside from the t-test variables, there were exploratory analyses to look for possible correlations between variables. A Pearson product moment correlation and regression analyses were used to determine relationships among anthropometric and power measures, stroke rates, and stroke lengths.

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All testing took place at a local competitive swimming pool. The varsity swim team that used the pool had the resources necessary for this research project to take place. The main equipment needed was a pool, the Power Rack, and an underwater camera. The school had given approval for the research to take place at their institution. In terms of research assistants, there were several graduate and undergraduates who were willing to assist the investigator with his study. In addition to the resources at the pool, several collegiate libraries provided additional means of supporting the research. These libraries contain an extensive collection of kinesiology journals and literature to search for past research that was pertinent to this project. The only limitation was access to some smaller journals and research reports. The investigator used interlibrary loans and contacts to gain access to these reports. Since the research took place through the cooperation of two institutions, both gave approval for the study through their respective human subjects committees. There were no major problems that impeded this study from taking place.

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CHAPTER 4 – RESULTS AND DISCUSSION

Results

Population description

There were 19 participants who initially participated in this study – ten males and nine females. Four participants dropped out of the study for various reasons – three chose to remove themselves before the final testing session; a fourth did participate in the final testing session, but was unable to complete it, and therefore not included in the final analysis. There were fifteen participants – eight male and seven female who did complete the full study. Fourteen of the participants were NCAA Division II collegiate swimmers while one male was a high school swimmer who trained with a local club team. All were injury free at the time of their participation in the study. One female had surgery on both shoulders in the past two years. However, she was regularly training for swimming, did not feel discomfort when swimming against the resistance of the Power Rack, and chose to continue with the study.

Characteristic data for the study population can be found in Table 4. The average age of the participants was 19.6 years. The average participant swam 6.5 practices a week, for 1.66 hours, and averaged 4600 meters per workout. Participants reported their average height to be 1.69 meters. They weighed 65.6 kilograms and had an arm length of 0.72 meters. Appendix E contains each participant's anthropometric measures along with the test data for each of their 18 Power Rack trials.

Out of the 15 who completed the study, eight specialized in freestyle, two specialized in breaststroke, one in butterfly, one in backstroke, and three specialized in both backstroke and freestyle.

	Population (n=15)		Males (n=8)		Females (n=7)	
Parameter	***Mean***	***Standard Deviation***	***Mean***	***Standard Deviation***	***Mean***	***Standard Deviation***
Age (years)	19.6	1.45	19.9	1.46	19.3	1.5
Weight (kg)	65.6	10.7	72.5	7.3	57.7	8.4
Height (meters)	1.69	0.11	1.77	0.05	1.59	0.05
Arm Length (meters)	0.72	0.07	0.76	0.06	0.67	0.03
Swimming Experience (years)	9.45	3.02	8.25	3.33	10.86	2.91
Practices (number per week)	6.5	2.23	6.00	2.14	7.14	2.34
Practice Length (hours)	1.66	0.31	1.63	0.23	1.71	0.39
Distance Swum Per Practice (meters)	4600	1400	4300	1280	4900	1560

Table 4: Population description

Out of these 15, seven were sprinters (events up to 100 meters), six were middle-distance swimmers (100-400 meter events), and two were distance swimmers (events over 400 meters). Seven of the participants said that they typically swam more with an I-Stroke, six typica

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six typically swam with an S-Stroke, one said that she had aspects of both, and one did not have immediate knowledge of his stroke pattern.

Power testing

The 18 trials for each participant can be found in Appendix E. To ensure that testing order did not influence the results, the participants performed the trials in a random order. The design of the experiment had each participant performing both strokes during the testing session. The participants were randomly chosen so that half performed the I-Stroke first (Group 1) and the other half performed the S-Stroke first (Group 2) resulting in 45 sets of data (i.e., 15 participants X 3 resistance levels). Average power output for each resistance level was not always calculated on the basis of three I-Strokes trials and three S-Stroke trials for each participant. Some trials were omitted when a participant failed to properly perform a designated stroke pattern. Out of the 24 sets of data where the S-Stroke was performed first, nine had the average power of the S-Stroke greater then that of the I-Stroke, 12 had the average power of the I-Stroke greater then that of the S-Stroke, and three in one participant (Male2) had data that could not be compared due to the two stroke styles used by the participants being too similar. Out of the 21 sets where the I-Stroke was performed first (Group 1), 17 had the average power of the I-Stroke greater then that of the S-Stroke, and four had the average power of the S-Stroke greater then that of the I-Stroke. Table 5 has a summary of the order of testing and which stroke style had a higher power output by resistance level for each participant. It should be noted that the participants were randomly assigned to perform either the I-Stroke first then the S-Stroke (Group 1) or the S-Stroke first then the I-Stroke (Group 2). The random assignment resulted in the majority of the female participants performing the S-Stroke first and the majority of the male participants performing the I-Stroke first.

Group 1: Testing the I-Pull then the S-Pull			
	Level 1	**Level 2**	**Level 3**
Male3	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Male4	$S_{avg} > I_{avg}$	$I_{avg} > S_{avg}$	$S_{avg} > I_{avg}$
Male5	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Male6	$I_{avg} > S_{avg}$	$S_{avg} > I_{avg}$	$S_{avg} > I_{avg}$
Male7	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Male8	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Female6	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$

Group 2: Testing the S-Pull then the I-Pull			
	Level 1	**Level 2**	**Level 3**
Male1	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Male2	N/A*	N/A*	N/A*
Female1	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Female2	$S_{avg} > I_{avg}$	$S_{avg} > I_{avg}$	$S_{avg} > I_{avg}$
Female3	$I_{avg} > S_{avg}$	$S_{avg} > I_{avg}$	$S_{avg} > I_{avg}$
Female4	$I_{avg} = S_{avg}$	$I_{avg} > S_{avg}$	$S_{avg} > I_{avg}$
Female5	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$	$I_{avg} > S_{avg}$
Female7	$S_{avg} > I_{avg}$	$S_{avg} > I_{avg}$	$S_{avg} > I_{avg}$

***Not compatible because designated I-Strokes were not able to be differentiated from S-Strokes.**

Table 5: Summary comparison of average power based on random assignment to stroke order

Stroke pattern analysis

Each trial was videotaped for stroke pattern analysis. The trials were viewed via a hook-up between a video camera and a monitor. The viewing and analysis of the trials took place at least a week after testing. When viewing the videotape, the researcher did not have prior

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have prior knowledge as to which stroke each participant was performing. The researcher viewed each trial multiple times to best describe the stroke characteristics and determine his opinion as to which stroke style it was. There was not a set number of times each trial was viewed as the trials were viewed enough to get a proper description of each trial and stroke style. The frame of reference for the technique analysis was the point on the wall where the video camera was positioned rather than the swimmer. The pull pattern was described relative to this point as this would eliminate any body rotation variance for each participant and focus just on the arm and hand.

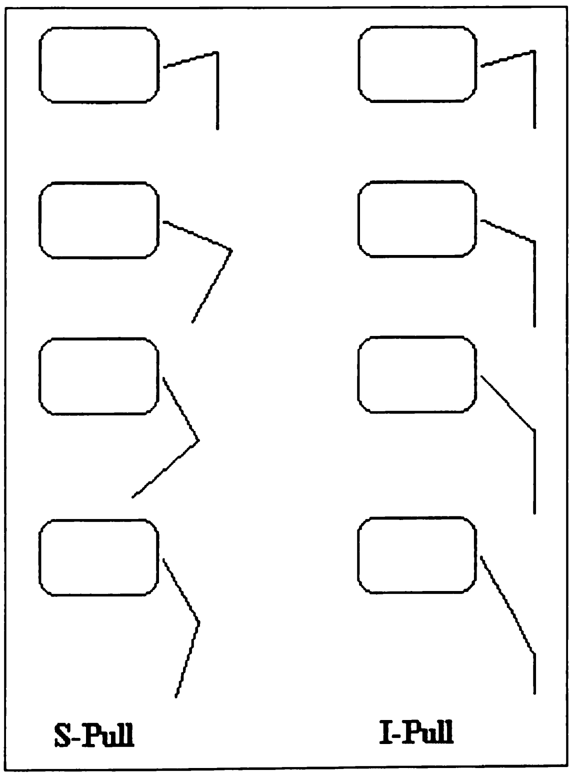

Figure 9: Schematic of rearview comparison of S-Pull and I-Pull

The criteria used to differentiate between the two stroke styles was to look at the lateral movement of the arm and hand. As each trial was viewed the lateral movement was nalyzed an

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analyzed and the amount (if any) determined if the stoke would be classified as the I-Stroke or the S-Stroke. Trials that showed a distinct lateral movement of the arm and hand were categorized as the S-Stroke; trials that had a minimal amount of lateral movement were categorized as the I-Stroke. The position of the arm could vary as two trials could be categorized as the I-Stroke with one taking place underneath the body and another taking place to the side of the body, with both having minimal lateral movement. Figure 9 provides a schematic example of how the two stroke styles may differentiate from each other.

It was observed that the participants primarily adhered to the prescribed stroke patterns and there was an observable difference between their I-Stroke and S-Stroke for the majority of participants. The analysis of the trials and general comments for each participant can be found in Appendix F

There were data that were not included in the calculations. There were some trials that were indistinguishable and the researcher could not determine which stroke style the participant was using. This is denoted by "I/S" in Appendix F; these data points were not included in subsequent t-test and correlation calculations. As an example, Figure 12 (Appendix G) is a comparison of the power output at lowest resistance level for the male participants. The stroke style for Male2's second set of data (I-Stroke) was deemed indeterminable and was not included on the chart; this is why there are only data points for the S-Stroke in Figure 12 for Male2. Following accordingly, the reason that there appears to be missing data points in Figures 13-17 is because those trials that were not verified as a certain stroke style were omitted.

In addition to the similarities in stroke patterns, the hook-up between the camera and underwater attachment became faulty for some of the trials for Female6 and Female7. Female6 had six S-Stroke trials that were not recorded cleanly and Female7 had eight trials (three S-Stroke and two I-Stroke) that were not recorded cleanly. From the trials that were recorded well, there was a discernable difference between the stroke styles for each of these two participants. Therefore, it was assumed that the remaining trials were correctly performed with the designated technique and therefore were included into the calculations.

The video of the underwater strokes provided some general trends and observations that occurred across all test participants. First of all, stroke patterns were done on an individual level – each swimmer's stroke evolved to what was best for him/her; there was a lot of variation between swimmers. For example, on the I-Pull there were swimmers who had a bent elbow but whose hands follows a straight path back while others had a more straight-arm pulls with minimal elbow flexion. The variation between swimmers did make it hard to compare the swimmers as a group but allowed for comparison between the two stroke styles for each individual participant.

The S-Pull features a large amount of elbow flexion during the pull. This is evident during the catch and as the hand comes back toward the midline of the body. Male3 had a wide catch and then his hand came back toward the body. There was also a pronounced out-sweep at the end of the stroke as the hand exited the water. In the I-Pull the hand stayed more to the lateral side of the body. Four participants (Male3, Male4, Male6, and Female2) showed a wider I-Pull as compared to the S-Pull; whereas Female1 had a straight-path pull that came under the body. Male1 had a deeper I-Pull which may have been due to the decrease in elbow flexion. Like the S-Pull, the I-Pull showed an out-sweep at the end of the stroke as the hand left the water.

Due to the set-up of the study, the legs of every test participant showed a negative vertical displacement in the water (i.e., their legs dropped due to the pull buoy and the ankle strap). After viewing the trials, it may have been better to have placed the pull buoy between the shanks to prevent the dropping of the legs rather then positioning the buoy between the thighs. At least five of the participants were seen doing a butterfly-type of kick in an attempt to get the legs higher in the water.

As the participants swam away from the wall, the hand entry and pulling did create turbulence and bubbles in the water which made viewing of the second half of each trial problematic. The turbulence was more pronounced during the S-Pull rather then the I-Pull. This could be due to the nature of the pull itself – the lateral sculling results in the hand changing directions to encounter still water. As the hand catches the still water, it will displace it, resulting in turbulence. The I-Pull, as it remains in a more unidirectional plane, encounters the still water at the beginning of the pull.

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Power comparison

The dependent *t*-test was used to compare sets of data to find if there was a statistical difference in power output between the two different stroke styles and the independent *t*-test was used to compare differences between different populations. It should be noted that the actual resistance used for each participant was individually determined on the basis of each participant's 1RM (i.e., 25, 50, and 75% of 1RM, within the limits of 2.3 kg increments). This resulted in different resistances being used for individuals for each resistance level. There were six scatter plots (Appendix G) produced to first visually examine the data. There were three plots for each gender – one at each of the three resistance levels. The data points were each successful trial for each participant. This included trials for Female6 and Female7 where video camera problems occurred. Aside from the data points (Appendix G), the plots also have dashed lines indicating the average power value for the two stroke styles, which can also be found in Table 6.

Resistance Level	Stroke Style	Average Power (W)		
		Population	Male	Female
1	I	44.0	50.1	37.7
	S	42.3	47.3	36.6
2	I	65.0	79.0	50.2
	S	62.5	74.3	49.1
3	I	78.5	98.1	57.8
	S	77.4	94.4	57.9

Table 6: Average power per resistance level and stroke style

The I-Stroke had a greater average power output then the S-Stroke at all resistance levels and demographics except for resistance level three for female participants. It is worth noting that, although the average powers at each level were numerically different between the two stroke styles, the magnitudes of the differences were relatively small. The highest difference was 3.7 watts at resistance level three for male participants. It should also be noted that as resistance level increased power output also increased for both the S-Stroke and I-Stroke.

$$t_{dep} = \Sigma(X_{Si}-X_{Ii})/SQRT[n(\Sigma(X_{Si}-X_{Ii})^2-(\Sigma(X_{Si}-X_{Ii}))^2)/(n-1)]$$

where: X_{Si} = power of S-Stroke for participant i

X_{Ii} = power of I-Stroke for participant i

n = number of data points (participants)

SQRT = square root

Equation 8: Dependent t-test calculation

$t_{ind} = (X_{1bar}-X_{2bar})/SQRT[(s_1^2/n_1+ s_2^2/n_2)$

where: X_{1bar} = average power of population 1,

X_{2bar} = average power of population 2

s_1^2 = standard deviation of population 1,

s_2^2= standard deviation of population 2,

n_1 = number of data points of population 1,

n_2 = number of data points of population 2,

SQRT = square root

Equation 9: Independent t-test calculation

After plotting the data, the dependent *t*-tests were calculated using Equation 8. The dependent *t*-test was used to compare sets of data to find if there were statistical differences in power output. The *t*-statistic at the 0.05 level was calculated for the following comparisons:

I-Stroke vs. S-Stroke at each resistance level for the entire population (Table 40),

I-Stroke vs. S-Stroke at each resistance level for male participants (Table 41),

I-Stroke vs. S-Stroke at each resistance level for female participants (Table 42),

The independent *t*-tests were calculated using Equation 9 to compare different populations and to find out if there were statistical differences between different groups. The *t*-statistic at the 0.05 level was calculated for the following comparisons:

Freestylers vs. non-freestylers at each resistance level for each stroke style for the entire population (Table 43),

Sprinters vs. non-sprinters at each resistance level for each stroke style for the entire population (Table 44) and,

Male vs. female at each resistance level for each stroke style for the entire population (Table 45).

The calculations for all *t*-tests were calculated using Excel via two different methods. The first method used Excel's function to calculate these values. The second method used hand-calculations with Excel to confirm the values. The hand-calculations verified the Excel function and all numbers were in agreement.

Dependent t-test				
	Resistence Level			t critical
	1	2	3	
Entire Population	1.62	2.00*	1.05	1.77
Males	2.62*	3.45*	1.78	1.94
Females	-0.12	0.09	-0.30	1.94
Independent t-test				
I-Stroke	Resistence Level			t critical
	1	2	3	
Sprinter vs Non-Sprinter	0.89	0.51	0.53	1.78
Freestyle vs Non-Freestyle	2.37*	2.28*	2.03*	1.78
Male vs Female	3.89*	4.45*	3.85*	1.78
S-Stroke	Resistence Level			t critical
	1	2	3	
Sprinter vs Non-Sprinter	1.67	0.66	0.54	1.77
Freestyle vs Non-Freestyle	1.03	1.74	1.50	1.77
Male vs Female	3.54*	4.34*	3.97*	1.77

***Denotes significant difference at $\alpha = 0.05$ level**

Table 7: t-test results

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This resulted in 27 different calculations (Appendix H) for the *t*-statistic which were calculated on the non-averaged data. Table 7 has a summary of the *t*-test results. Out of these 27 values, there were 12 which showed a significant difference (denoted by asterisks in Table 7) at the 0.05 level:

the I-Stroke produced more power than the S-Stroke for the entire population at resistance level 2,

the I-Stroke produced more power than the S-Stroke for the males at resistance levels 1 and 2,

freestylers produced more power than non-freestylers with the I-Stroke at resistance levels 1, 2, and 3

males produced more power than females with the I-Stroke and S-Stroke at resistance levels 1, 2, and 3

All other sets of comparisons did not show a statistical difference between the I-Stroke and the S-Stroke.

There is an obvious inherent difference between males and females. The *t*-test calculations were done to compare these two populations to confirm this difference, which the data did show. It would have been worth noting if the data did not show a difference between males and females.

A repeated measures ANOVA was done to further explore the relationship between the I-Stroke and the S-Stroke. The ANOVA charts were calculated using SPSS statistical sof

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software. The F-statistic was calculated to compare the I-Stroke and S-Stroke and can be found in Appendix I. The ANOVA resulted in no difference between the two strokes for all participants, the male participants, or the female participants. The ANOVA does follow inline with the t-test results which gave 6 out of 9 comparisons with no statistical difference.

Correlation relationships

The data was analyzed for possible correlations between variables. The dependent variable throughout the study was power generated by experienced swimmers, as measured in watts on the Power Rack. Power, measured on each level of resistance (i.e., 25, 50, and 75% of 1RM) for each stroke pattern (i.e., S-Stroke and I-Stroke), was correlated with the height, weight, and arm length of the participants. As there were three trials at each resistance level and stroke pattern, the averages of these were used in the correlation calculations. These correlations were done three times – once on the population as a whole, a second time on the male population, and a third time on the female population. As noted earlier, the trials with an indeterminable stroke style were not included in these calculations.

A scatter plot for each of the 54 correlation sets was constructed. Each plot can be found in Appendix J. After the data were plotted, both the r and R^2 statistics were calculated for each data set. The values for R^2 are included on each of the scatter plots in Appendix J and the r values are included in Table 8. The r statistic tells how strong a relationship existed between the two variables; the closer the *r* statistic is to 1.0 (or -1.0), the stronger the relationship is. A summary of all correlation results can be found in Table 8.

Stroke Type		I			S		
Resistance Level		1	2	3	1	2	3
Entire Population	Height	0.71	0.69	0.65	0.56	0.64	0.61
	Weight	0.67	0.68	0.67	0.69	0.63	0.69
	Arm Length	0.58	0.64	0.60	0.44	0.54	0.51
Males	Height	0.11	-0.07	-0.06	-0.23	-0.21	-0.27
	Weight	0.30	0.29	0.23	0.33	0.09	0.18
	Arm Length	0.09	0.26	0.23	0.01	0.08	0.07
Females	Height	0.09	0.07	0.13	-0.15	-0.06	0.06
	Weight	0.27	0.30	0.51	0.42	0.33	0.65
	Arm Length	0.01	-0.10	-0.10	-0.38	-0.40	-0.42

Table 8: Correlation summary, *r* statistic

Examining the population as a whole, height and weight correlate most strongly to power produced by the two stroke styles. Height and weight have correlations between 0.56 and 0.71 across stroke type and resistance level. Based on the data collected, weight corresponds equally as strong as height to both stroke types. Arm length has the weakest correlation amongst the three measured variables. As seen with height, the correlations between arm length and power with the I-Stroke are stronger then between arm length and power with the S-Stroke. The results here, correlating the entire population, are to be expected. Males and females do have physical biological differences. The inherent nature of these differences automatically gives rise to the resulting correlations, while at the same time it is hard to draw notable conclusions from these relationships. It is more worthwhile to look at gender-only relationships.

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When the populations are analyzed by gender, the correlations become much weaker. Weight has the strongest relationship to swimming power in both genders, yet the level of correlation has dropped in comparison to the population correlation. The average (across all three resistance levels and stroke types) *r* statistic between weight and power for all participants is 0.67 for both stroke types; the values of these types of averages fall to 0.27 (I-Stroke) and 0.20 (S-Stroke) for the male participants and to 0.36 (I-Stroke) and 0.47 (S-Stroke) for the female participants. The data does suggest that weight may contribute more to power output in females than males. Height actually indicates a possible inverse relationship with power for males. Out of the six correlation values for the males all but the I-Stroke at resistance level 1 have a negative correlation to swimming power. The females have negative correlations only for the S-Stroke at resistance levels 1 and 2. These correlations between height and power are weak. Another factor affecting the relationship between height and power is that height was reported by participants rather then measured by an anthropometrist. Slight variations in the height may have resulted in stronger or weaker correlations. For the males the S-Stroke shows a stronger relationship then the I-Stroke. Male arm length has a weak positive relationship with swimming power. The I-Stroke correlates better with arm length then the S-Stroke does. Female arm length has a negative relationship with power with the S-Stroke correlating stronger then the I-Stroke.

Discussion

The main purpose of this study was to find out if there is a difference in the amount of power generated by two different freestyle stroke patterns – the straight I-Stroke and the

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curved S-Stroke. Aside from this question, there were several sub-questions which investigated the difference in power generated by freestylers compared to non-freestylers, and sprinters compared to non-sprinters. In addition, there were exploratory data gathered to relate the power generated to different anthropometric measures.

The data that was compiled during this study was inconclusive in determining a statistical difference for power generated between the I-Stroke and the S-Stroke. Three out of nine comparisons did result with the I-Stroke generating statistically more power than the S-Stroke; whereas six comparisons resulted with the two strokes being statistically equal. This suggests that swimmers can use either stroke to perform equally as well. Examining the data further, does give some support in favor of using the I-Stroke over the S-Stroke to maximize power output. At each of the three resistance levels for the entire population, the I-Stroke had a higher average power then the S-Stroke. The power differences between the two strokes were 1.7 W for resistance level 1, 0.8 W for resistance level 2, and 1.1 W for resistance level 3.
Examining the data based on gender gave similar results. The I-Stroke has the higher average power for males with differences of 2.8 W, 1.3 W, and 3.7 W at resistance levels 1, 2, and 3, respectively. The I-Stroke has the higher average power for females at resistance levels 1 and 2 with differences of 1.1 W and 0.8 W, respectively. Out of the nine total comparisons (entire population, male, female) the only instance in which the S-Stroke had a higher average power was for the females at resistance level 3 with a difference of 0.1 W.

These differences are small but when put in context of the purpose of the I-Stroke, it may be more beneficial to use. Ito's theory (2004) behind the I-Stroke states that it will provide more power while being less efficient. The population demographic that would most likely use the I-Stroke is freestyle sprinters who specialize in the 50 and 100 meter events. The results of competitions in these events are determined by tenths or even hundredths of a second, which brings up the comparison of statistical significance versus practical significance. While there were only three comparisons that resulted with the I-Stroke being statistically better than the S-Stroke for power generation, the data does lean toward the I-Stroke being more beneficial. The differences between the I-Stroke and the S-Stroke, however small, could be enough to make a swimmer faster then ever before. Athletes are looking for every possible advantage that they can get to put them ahead of their previous best and their competitors. If a swimmer is able to generate even just a small amount of power more during these events, regardless if it is statistically significant or not, it could be the difference they are looking for.

Examining the participants by stroke specialties provides interesting results. The data (Table 43, Appendix H) indicates that at all three resistance levels there is a significant difference in the power generated with the I-Stroke between those who specialize in freestyle and those who specialize in other strokes. This indicates that those swimmers whose best events are freestyle events generate more power using the freestyle stroke than those whose best events are strokes other then freestyle. Freestyle is the fastest of competitive strokes and those who practice it more are more likely to produce more power. For freestylers the I-Stroke consistently produced more power than the S-Stroke while

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while for non-freestylers the S-Stroke consistently produced more power. Since the non-freestylers are focusing on other strokes, they are more likely to adopt a stroke technique that is using less energy (i.e., the S-Stroke). Each swim coach has a different way to train his/her athletes, but most swimmers are going to swim the majority of their yards using the freestyle stroke. The energy that is conserved while using the S-Stroke can then be used later during a workout on the swimmers' main stroke.

When the participants are examined by distance of events that they swim (Table 44, Appendix H), there were no significant differences between sprinters and non-sprinters. These results do come as a bit of a surprise as sprinters are traditionally the strongest and fastest swimmers. Hawley et al. (1992) and Sharp et al. (1982a, 1982b) have shown that power is most important at shorter distances. Non-sprinters are trying to maximize speed for the longest possible time. While there was not a statistical difference between the groups, the sprinters were producing more power at each resistance level regardless of the stroke style they used. A possible follow-up study would be to examine just males or females and the break-down between sprinters and non-sprinters.

One area which produced statistical differences was between female swimmers and male swimmers. The male swimmers produce more power at each resistance level and with each stroke technique. These results follow that of Simmons (2003) and Hawley et al. (1992) who each showed that males produce more power than females. Simmons accounted the difference in power to the added muscle that male swimmers have compared to female swimmers. The current study did not look at body composition, but, since it follows that on average females have a higher proportion of body fat and thus a lower percentage of muscle, this is one way to account for the difference between men and women. The current study also found that body weight best correlates to swimming power. Since the males' average body weight in the current study outweighed the females' average body weight (72.5 kg to 57.7 kg), body weight may be another factor that affects the differences in power generation between females and males.

After the participants completed their trials, some provided unsolicited feedback on the different strokes, the experimental setup, and how they performed. As this information was not part of the design, it was not recorded, but should be noted. Part of the Swimming Background Questionnaire asked if their pull pattern was more curvilinear (S-Stroke) or straight (I-Stroke). Some of the participants commented that one stroke style was more natural, and thus the favored stroke. The intervention and experiment had an unintended consequence – it made the participants more aware of their stroke technique and what they were actually doing in the water. The design of the trials (no push-off to start) was hard for a couple of the participants and the resistance on the Power Rack was quite a bit lower than what they use in a training environment. There were also random comments from participants about the trials regarding the resistance and not knowing how much resistance to expect for each trail. This often occurred after a trial as the participants vocalized whether it was light, medium, or high resistance.

One area that was not controlled for was possible researcher expectation when analyzing and viewing the stroke patterns. The researcher did not have any perceived bias in terms of the analysis and expectations of the results. As Ito's (2004) initial hypothesis was that the I-Stroke produces more power than then S-Stroke, there is a chance that there was a subconscious bias in favoring the I-Stroke. This is a factor that would need to be corrected for in any future studies.

The correlation results show that of the three anthropometric measures, weight correlates best to power output. These results agree with Simmons (2003) who showed a positive correlation between subject weight and overall speed in over 600 male and female swimmers. The population of the current study was experienced swimmers. These athletes have been participating in the sport, on average, for over nine years. The combination of swimming and weight training has resulted in participants whose muscles are conditioned to excel in the sport of swimming. As body composition was not analyzed for this study, it can be hypothesized that those participants who have the higher weight possess a greater amount of swimming-specific muscle.

The influence of arm length and height of the participants is less influential on power output then weight. Previous work done relating anthropometric variables to swimming velocity have provided conflicting results. Chatard et al. (1990) found that there is no relationship between height and arm length to swimming velocity. Chatard did attribute this lack of a relationship to the homogeneous nature of the population used for the study. Grimston and Hay (1986), on the other hand, found that arm length has a positive correlation to stroke length which in-turn correlates to velocity. They looked more closely at anthropometric measures and included cross-sectional area in her study.

The gender correlations are less consistent to height and arm-length. There are several negative correlations occurring in both the male and female population. The correlations for the entire population have moderate relationships while those that are gender-specific have much weaker relationships. The discrepancy in the data can be attributed to the number of participants used in the study. There were 15 total participants and when these were divided into half by gender, the low number of participants affects statistical significance of the results. There needs to be more work done with larger populations of single-gender studies, along with more precise measures of height to provide a clearer relationship between arm length and height to power output.

The data was examined to look for gender differences between the I-Stroke and S-Stroke with the anthropometric measures. For males, the S-Stroke had a stronger negative correlation to height while the I-stroke had no discernable relationship; with the females, the correlations were so weak that no relationship existed between height and either of the stroke types. The data indicates that shorter males are producing more power with the S-Stroke as compared to their taller counterparts. Weight had positive correlations to both stroke types for both genders. Heavier males may benefit more from using the I-Stroke while heavier females may produce more power using the S-Stroke. Body composition was not analyzed, but, since there are differences between genders (women having a higher percentage of body fat), it is possible that body composition affects which stroke style is better for each gender. Arm length had conflicting results when it did come to gender. The males had a positive correlation to arm length with the I-Stroke, while tha

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while the S-Stroke had a non-existent correlation. The females had a negative correlation to arm length with the S-Stroke and a very weak negative correlation to the I-Stroke. Both genders with longer arms would benefit from using the I-Stroke over the S-Stroke.

Taking the gender, anthropometric, and stroke types into consideration, one could develop a model for an ideal swimmer from this study. Males who use the I-Stroke may produce the most power if they were heavier and have shorter arms. Males who use the S-Stroke may produce the most power if they were shorter and heavier. Females who use the I-Stroke may produce the most power if they were taller and heavier. Females who use the S-Stroke would produce the most power if they were shorter, heavier, and had shorter arms.

There is a moderate-to-strong correlation between power and speed. This study did not directly measure a participant's time and speed for a competitive swimming distance. The initial questionnaire, however, did ask for each participant's best time (overall and in the past year) in the 50-yard freestyle event. The correlations can be found in Table 9.

	Best 50 time	I-Stroke			S-Stroke		
		Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Entire Population	Within the past year	-0.83	-0.82	-0.82	-0.73	-0.75	-0.75
	Lifetime	-0.85	-0.86	-0.86	-0.79	-0.81	-0.82
Males	Within the past year	-0.83	-0.60	-0.64	-0.50	-0.41	-0.44
	Lifetime	-0.83	-0.70	-0.73	-0.67	-0.47	-0.54
Females	Within the past year	-0.34	-0.29	-0.35	-0.22	-0.13	-0.22
	Lifetime	-0.26	-0.24	-0.41	-0.30	-0.23	-0.45

Table 9: Correlation between best time in 50 yard freestyle and power generated

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There is a negative correlation between the two variables, meaning that the faster performances were associated with greater power production. This suggests that the fastest swimmers produce the most power and increases in swimming-specific power may result in improved performance. An evaluation of the correlations reveals that the I-Stroke correlates slightly stronger to performance than the S-Stroke for most of the population. The only instance in which the S-Stroke has a better correlation is when the times are correlated to the females best ever time in the 50 freestyle. The best 50 time in the past year may be more applicable as it describes recent success. Females also peak at a younger age and it is not uncommon to have college-age female swimmers whose best times are from when they were younger. The correlations suggest and give credence to the idea that the I-Stroke may be better suited to producing speed and power in the sprint events.

It should be noted when examining correlation results, correlation does not necessarily indicate causation. In this study, weight had the highest correlation to the amount of swimming power generated with either stroke technique. This does not necessarily mean that the more a swimmer weighs the more power he/she is going to generate. What it does mean is that those swimmers who weight more will have an increased possibility of generating more swimming power, especially if they have a relatively low percent of body fat and a relatively higher percent of lean body mass. There is a ceiling, however; if these results are extrapolated upward, there will come a certain body weight (probably dependent on each individual) where it becomes a hindrance to generating swimming power. This would fall in line with the athlete's body mass index and the percentage of fat free mass to total body mass. There is a limit as to how body mass index would affect the power production.

The study did help to establish face validity for the Power Rack. There was not a statistic reliability and validity test done with the Power Rack but it was used in a minimum of 270 separate trials throughout the study. The Power Rack is a simple and easy device to use. It is normally used as a training device to develop sprint speed, strength, and power. It should be noted that as the resistance level increased so too did the power output for both the I-Stroke and S-Stroke for all participants in this study. This fact could be used by swimming coaches in training their athletes. The current study, along with the previous studies (Simmons, 2003; Johnson et al., 1993), has shown that the Power Rack is a valid device to be used in a research setting.

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CHAPTER 5 – CONCLUSIONS AND FUTURE STUDIES

Conclusions

The aim of this study was to explore two different stroke styles and to find any potential differences in the amount of power generated by the two. The data in this study did not show that one stroke style produced more power than the other. This study was the first of its kind – there are no published studies that have looked at stroke patterns and how they affect power. There have been studies that have examined power, but these focused on different ways to measure swimming power and how these related to other swimming characteristics such as swimming velocity and anthropometric measures.

While there was not a statistical difference between the power output generated via the S-Stroke and the I-Stroke, the data suggests that the I-Stroke may be more beneficial then the S-Stroke for generating power. The I-Stroke consistently provided higher power values over the S-Stroke. There were 72 pairs of data comparing the two strokes. When these pairs were matched and compared, the I-Stroke had a higher value 61% of the time (44 out of 72), the S-Stroke yielded a higher value 36% of the time (26 out of 72) and 3% of the time the results were equal (2 out of 72). At resistance levels 1 and 2, the average power output of the I-Stroke was higher then that of the S-Stroke. The I-Stroke had higher correlations to anthropometric measures of arm length, height, and weight; as well as to historical sprint performance times of the participants.

Stroke patterns vary from swimmer to swimmer. Each swimmer typically adopts a stroke style that is biomechanically best for him/her. While there are differences between individuals, there are some generalities that appear between the two stroke styles discussed in the current study. The S-Stroke featured elbow flexion that allowed for the sculling motions that is inherent to this style. The elbow flexion and lateral movement of the S-Stroke resulted in a stroke that comes underneath the body more. The I-Stroke, while exhibiting some elbow flexion, is a wider stroke and travels more laterally in reference to the body. Both strokes do have an upsweep at the end during the transition from the pull to the recovery above the water.

Limitations and Future Studies

There were several limitations to this study. The first is the number of participants. There were a couple of participants who did not participate for the duration of the study. A greater number of participants would contribute to a better chance of statistical significance. Along these lines, more participants would allow for more comparative statistical measures to take place such as additional correlations, causal relationships, and more confidence in the results.

The other major limitation of the study was the video recording of the underwater strokes. The underwater camera was only capable of recording the strokes in two dimensions. The video camera was oriented behind the swimmers and captured the participants swimming away from the wall. This camera angle allowed the viewer to differentiate between the I-Stroke and S-Stroke by examining the degree of lateral movement of the hand and arm away from the center line of the body. The depth and the length of the stroke were unable to be measured with this camera orientation. An over

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overhead or underneath camera angle would have helped to establish these differences between the two strokes.

The study does open the possibility to additional studies to further look at the relationship between stroke pattern and power. One of the goals of this study was to serve as a base for future analysis of stroke patterns and power. This is a new area of swimming research and the swimming community can use this study as a springboard to additional studies. Here are some of the possible research questions that could extend from this study:

Is there statistical proof by gender that the I-Stroke produces more power than the S-Stroke?

What are the biomechanical and physiological principals that produce more power with a certain stroke?

Is there a significant correlation between body composition and swimming power?

Aside from these questions, the current study could be repeated or amended in a couple of different ways. Recruiting a higher number of research participants would improve the statistical power of the study. A higher number of participants would also allow a study to take place where the participants are divided into multiple groups – one doing the I-Stroke and one doing the S-Stroke; the results between the two groups would then be compared and the participants would not have to worry about learning two different stroke styles. The study could be repeated with a higher participant count and with just one gender. A single-sex study would eliminate any gender bias and have results that are valid f

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valid for one gender. Another option would be to do a longer study of 6, 8, 10, or 12 weeks, although that could impact participant retention. A last possible study would be to look at the long-term benefits of either stroke. As proposed, the I-Stroke is to be used for short sprints – would it be beneficial to use it for longer events as well?

The research study opened up the possibility that a straight-path pull produces more swimming power then a curved-path pull. While there is no statistical difference between the two strokes; when the body of data is taken as a whole, it suggests that experienced swimmers are able to produce more power with the I-Stroke than with the S-Stroke. The study does lay the ground work for more in-depth research to more fully examine the relationship between the two stroke styles and the amount of power that may be generated with each one.

APPENDICES

APPENDIX A -- Informed Consent Form

Summary of research
The purpose of this study is to measure the power output generated by two different freestyle swimming stroke patterns. Participants will perform a series of 18 swims on the Power Rack (a weight stack and cable-pulley system). Half of the swims will be done with a conventional S-Pull stroke and half will be done with a straight I-Pull stroke.

Permission to videotape
Participants who choose to participate in this study will be videotaped. The video will be transferred into digital form for analysis and characterization of stroke technique. The video will be kept for a to-be-determined amount of time and then destroyed. You have the option to request the video to be destroyed in the event that you withdraw from the study.

Estimate of time
There will be two parts to this study. The first part will consist of an instructional period and Power Rack 1RM test. The instructional period will go over the I-Pull technique and some drills to help in mastering it. The 1RM test on the Power Rack will increase resistance each trial until the participant is unable to complete a trial. This first part of the testing should take no more then two hours. The second part of the testing involves a series of anthropometrical measurements (height, weight, and arm length), and the 18 Power Rack trials. This second part of the test should take no longer then 90 minutes.

Voluntary participation
Participation in this research is strictly voluntary. As a participant, you have the right to refuse from participating in certain parts of the study and at any time you may withdraw from the study without penalty.

Confidentiality and anonymity
As a participant, your confidentiality and anonymity as a participant will be upheld. Written reports and publications will list participants as *Participant*. The principle investigator and those assisting him with the research (advisory committee and research assistants) will have access to the data and will have knowledge of participants. As a participant, you have a right to the data collected during research. Your privacy will be protected to the maximum extent allowable by law.

Contact persons
The principle investigator is Dr. Eugene Brown who can be contacted via phone at 517.353.6491 or via email at ewbrown@msu.edu. The person conducting the research will be Mark Dziak, a graduate student in the department of Kinesiology at Michigan State University. Mr. Dziak can be contacted via phone at 216.773.1232 or via email at dziakmar@msu.edu. If you have questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – Peter Vasilenko, Ph.D., Chair of the University Committee

on Research Involving Human Subjects (UCRIHS) by phone: 517.355.2180, fax: 517.432.4503, e-mail: ucrihs@msu.edu, or regular mail: 202 Olds Hall, East Lansing, MI 48824.

Experimental procedures
As a participant you will use the Power Rack. The Power Rack is a device that allows swimmers to swim against an adjustable amount of weight. There is a belt that is tethered to a cable and to the Power Rack. The Power Rack may be a new device for you to use as a swimmer. There may be some slight discomfort from the positioning of the belt and swimming against weight. Standard anthropometrical measures of height, weight, and arm length will be gathered for participant characteristic and data analysis.

Risk of physical injury to participants
If you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for your research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of what are paid by your insurance, including deductibles, will be your responsibility. Financial compensation for lost wages, disability, pain or discomfort is not available. This does not mean that you are giving up any legal rights you may have. You may contact Mark Dziak via phone at 216.773.1232 or via email at dziakmar@msu.edu with any questions.

Copy of consent form
Participants will be provided with a copy of this form for their personal records.

Your signature below indicates your voluntary agreement to participate in this study

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APPENDIX B – Swimming Background Questionnaire

Name:

Date of birth:

Number of years swimming competitively:

Best 50 yard freestyle time:

Best 50 yard freestyle time in the past year:

What is your stroke specialty?

What is your distance specialty (sprint (50-100), middle (100-500), distance (500+))?

Approximate number of yards/meters (specify) swum per practice in the past month:

Approximate number of practices per week and their duration (time) in the past month:

Would you describe your freestyle pull pattern as more of a curvilinear pull or more of a straight pull (circle one)?

Curvilinear Straight

APPENDIX C -- Drills and Sets for Teaching the Two Stroke Styles

I Stroke

The main drill used to teach the I-Stroke was the Vasa Drill. In this drill the swimmer lies prone in the water with their arms extended above the head and a pull buoy between the ankles. The swimmer would initiate the pull and focus on keeping the hand and forearm facing rearward. The swimmers were also told to use the black line on the bottom of the pool to trace and reinforce the straight nature of the I-Pull. This drill was done slowly so that the swimmer can concentrate on the stroke mechanics. The drill can be done with both arms at the same time or by alternating arms.

S-Stroke

Sculling was used to teach the S-Pull. The sculling drills were used one at a time and in combination with each other. Sculling was done in the following ways:
Front Scull: Swimmer prone in the water, arms straight and extended above the head.

High Elbow Scull: Same position as the front scull but the elbows are bent and the hands & forearms are oriented toward the bottom of the pool

Middle Scull: Similar to the High Elbow Scull but with the arms in-line with the shoulders. The hands & forearms are still oriented to the bottom of the pool

Back Scull: Swimmer is prone in the water with the arms at the side. The sculling motion initiates with the arms pointing to the bottom of the pool and the swimmer pushes the water up and out towards the hips.

Swimming Sets

All drills were done in repetitions of 25 or 50 yards. An example of a set from the first week for the S-Stroke was:
Set 1: 5 x {4 x 25 @ :40 Interval}. Each set was a different scull drill with the last set being swim focusing on the S-Pull.
For the I-Stroke, an example set was:
Set 2: 10 x 50 @ 1:10 Interval. The first 8 were done using the Vasa Drill while the last 2 were swum focusing on a straight I-Pull.

Each main technique set was a variance of one of the above two sets. The second week started to incorporate speed. For example *Set 1* from above could be repeated but with the last 4 repeats, the swimmers would get faster on each one while maintaining the proper S-Stroke pattern. Weeks 3 and 4 saw the amount of drilling reduced while putting a larger emphasis on speed. For the I-Stroke the swimmers might do *Set 2* from above with the first four repeats performed with the Vasa Drill; the last six repeats would have the swimmer sprint the first 15 yards of the repeat with the proper stroke style.

APPENDIX D -- Data Collection Forms

Subject:		Height (m):		Resistance Level 1		
Stroke (S or I):		Weight (kg):		Resistance Level 2		
PR 1-RM:		Arm Length (m):		Resistance Level 3		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count
Trial 1						
Trial 2						
Trial 3						
Trial 4						
Trial 5						
Trial 6						
Trial 7						
Trial 8						
Trial 9						
Subject:		Height (m):		Resistance Level 1		
Stroke (S or I):		Weight (kg):		Resistance Level 2		
PR 1-RM:		Arm Length (m:		Resistance Level 3		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count
Trial 10						
Trial 11						
Trial 12						
Trial 13						
Trial 14						
Trial 15						
Trial 16						
Trial 17						
Trial 18						

Figure 10: Anthropometric and power data sheets

Subject:					
Trial 1		Trial 2		Trial 3	
Trial 4		Trial 5		Trial 6	
Trial 7		Trial 8		Trial 9	
Trial 10		Trial 11		Trial 12	
Trial 13		Trial 14		Trial 15	
Trial 16		Trial 17		Trial 18	

Figure 11: **Stroke technique analysis form**

APPENDIX E – Testing Results

Subject:	Female1	Height (m)	1.61	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	52.2	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.70	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	20	12.81	12.85	12.75	12.80	21	66.7
Trial 2	10	10.08	10.07	10.14	10.10	17	42.3
Trial 3	20	12.41	12.42	12.49	12.44	21	68.7
Trial 4	10	9.78	9.85	9.81	9.81	17	43.5
Trial 5	15	10.93	10.90	10.82	10.88	19	58.9
Trial 6	15	11.33	11.24	11.30	11.29	19	56.8
Trial 7	20	13.05	13.15	13.00	13.07	21	65.4
Trial 8	10	9.84	9.83	9.90	9.86	17	43.3
Trial 9	15	11.66	11.70	11.75	11.70	20	54.8
Subject:	Female1	Height (m)	1.61	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	52.2	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.70	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	15	10.80	10.75	10.85	10.80	18	59.3
Trial 11	10	9.87	9.90	9.95	9.91	17	43.1
Trial 12	15	11.47	11.40	11.38	11.42	18	56.1
Trial 13	20	12.31	12.30	12.40	12.34	21	69.3
Trial 14	15	10.20	10.30	10.17	10.22	18	62.7
Trial 15	10	9.89	9.85	9.83	9.86	18	43.3
Trial 16	20	12.56	12.62	12.55	12.58	21	67.9
Trial 17	20	12.29	12.30	12.22	12.27	21	69.6
Trial 18	10	9.82	9.80	9.87	9.83	17	43.5

Table 10: Female1 data

Subject:	Female2	Height (m)	1.55	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	57.2	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.61	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	15	10.22	10.10	10.15	10.16	20	63.1
Trial 2	10	9.78	9.76	9.71	9.75	20	43.8
Trial 3	20	11.84	11.99	11.97	11.93	24	71.6
Trial 4	15	10.80	10.72	10.93	10.82	22	59.2
Trial 5	10	10.07	10.01	9.97	10.02	22	42.7
Trial 6	10	10.36	10.45	10.33	10.38	22	41.2
Trial 7	20	12.52	12.66	12.70	12.63	25	67.7
Trial 8	15	12.07	12.10	11.97	12.05	24	53.2
Trial 9	20	14.33	14.50	14.55	14.46	28	59.1

Subject:	Female2	Height (m)	1.55	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	57.2	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.61	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	15	11.11	11.18	11.07	11.12	24	57.6
Trial 11	20	13.71	13.62	13.58	13.64	28	62.7
Trial 12	20	14.09	14.01	14.15	14.08	28	60.7
Trial 13	20	15.21	15.42	15.36	15.33	28	55.7
Trial 14	10	10.89	10.95	10.79	10.88	22	39.3
Trial 15	10	10.80	10.93	10.97	10.90	22	39.2
Trial 16	15	12.36	12.31	12.21	12.29	23	52.1
Trial 17	10	10.97	11.05	10.92	10.98	23	38.9
Trial 18	15	12.19	12.13	12.20	12.17	25	52.6

Table 11: Female2 data

Subject:	Female3	Height (m)	1.60	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	49.0	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.70	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	20	15.70	15.63	15.62	15.65	22	54.6
Trial 2	15	13.18	13.20	13.27	13.22	20	48.5
Trial 3	10	12.00	12.05	11.98	12.01	18	35.6
Trial 4	15	13.82	13.90	13.91	13.88	20	46.2
Trial 5	10	11.78	11.77	11.68	11.74	18	36.4
Trial 6	15	15.00	15.08	15.03	15.04	20	42.6
Trial 7	20	18.38	18.18	18.32	18.29	25	46.7
Trial 8	10	13.24	13.24	13.20	13.23	18	32.3
Trial 9	20	19.76	19.74	19.81	19.77	26	43.2
Subject:	Female3	Height (m)	1.60	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	49.0	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.70	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	10	11.83	11.80	11.76	11.80	17	36.2
Trial 11	10	12.27	12.21	12.33	12.27	19	34.8
Trial 12	15	15.24	15.33	15.24	15.27	22	42.0
Trial 13	15	15.63	15.62	15.51	15.59	23	41.1
Trial 14	15	15.81	15.85	15.76	15.81	21	40.5
Trial 15	20	16.10	16.09	16.22	16.14	28	53.0
Trial 16	20	20.05	20.16	19.98	20.06	29	42.6
Trial 17	20	19.56	19.50	19.43	19.50	30	43.8
Trial 18	10	12.57	12.60	12.54	12.57	17	34.0

Table 12: Female3 data

Stroke (S or I):	S	Weight (kg)	74.8	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.65	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	10	8.99	8.85	9.04	8.96	13	47.7
Trial 2	20	9.78	9.88	9.91	9.86	16	86.7
Trial 3	20	11.29	11.32	11.47	11.36	18	75.2
Trial 4	15	10.81	10.88	10.70	10.80	16	59.4
Trial 5	20	11.55	11.38	11.40	11.44	18	74.7
Trial 6	10	10.41	10.31	10.50	10.41	16	41.1
Trial 7	15	11.28	11.39	11.17	11.28	17	56.8
Trial 8	15	11.63	11.60	11.79	11.67	17	54.9
Trial 9	10	10.33	10.32	10.41	10.35	16	41.3

Subject:	Female4	Height (m)	1.63	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	74.8	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.65	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	10	9.51	9.36	9.47	9.45	14	45.2
Trial 11	10	10.34	10.48	10.30	10.37	16	41.2
Trial 12	15	10.48	10.29	10.32	10.36	15	61.8
Trial 13	20	11.38	11.40	11.23	11.34	18	75.4
Trial 14	20	12.09	12.25	12.02	12.12	19	70.5
Trial 15	20	12.32	12.16	12.17	12.22	19	69.9
Trial 16	10	9.69	9.81	9.85	9.78	18	43.7
Trial 17	15	11.01	10.91	11.14	11.02	18	58.2
Trial 18	15	11.37	11.31	11.49	11.39	17	56.3

Table 13: Female4 data

Subject:	Female5	Height (m)	1.65	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	53.1	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.69	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	15	16.36	16.27	16.97	16.53	19	38.8
Trial 2	15	15.61	15.71	15.85	15.72	19	40.8
Trial 3	10	14.48	14.30	14.41	14.40	18	29.7
Trial 4	20	18.83	19.05	18.93	18.94	24	45.1
Trial 5	10	14.27	15.15	15.39	14.94	17	28.6
Trial 6	15	15.83	15.82	16.00	15.88	19	40.3
Trial 7	20	19.54	19.43	19.38	19.45	23	43.9
Trial 8	10	14.14	14.26	14.10	14.17	18	30.2
Trial 9	20	18.93	19.00	19.05	18.99	23	45.0

Subject:	Famale5	Height (m)	1.65	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	53.1	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.69	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	20	14.53	14.50	14.62	14.55	21	58.7
Trial 11	10	11.71	11.65	11.79	11.72	16	36.5
Trial 12	20	17.25	17.38	17.33	17.32	23	49.3
Trial 13	10	12.42	12.52	12.60	12.51	17	34.1
Trial 14	15	12.98	13.07	12.94	13.00	18	49.3
Trial 15	10	12.07	12.18	12.00	12.08	17	35.4
Trial 16	20	15.95	15.83	15.86	15.88	21	53.8
Trial 17	15	13.31	13.19	13.33	13.28	18	48.3
Trial 18	15	13.62	13.69	13.58	13.63	18	47.0

Table 14: Female5 data

Subject:	Female6	Height (m)	1.50	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	59.0	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.69	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	15	9.88	9.95	9.85	9.89	14	64.8
Trial 2	10	9.73	9.60	9.61	9.65	14	44.3
Trial 3	10	10.26	10.30	10.42	10.33	15	41.4
Trial 4	20	11.81	11.75	11.72	11.76	18	72.7
Trial 5	20	12.44	12.35	12.57	12.45	18	68.6
Trial 6	15	11.16	11.09	11.20	11.15	16	57.5
Trial 7	15	12.04	12.18	12.02	12.08	17	53.0
Trial 8	20	13.50	13.63	13.57	13.57	19	63.0
Trial 9	10	10.90	10.99	10.85	10.91	16	39.1

Subject:	Female6	Height (m)	1.50	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	59.0	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.69	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	15	14.19	14.17	14.23	14.20	17	45.1
Trial 11	20	15.76	15.80	15.62	15.73	19	54.3
Trial 12	20	15.58	15.70	15.58	15.62	18	54.7
Trial 13	15	12.34	12.39	12.44	12.39	15	51.7
Trial 14	20	14.73	14.60	14.63	14.65	18	58.3
Trial 15	15	13.58	13.47	13.69	13.58	17	47.2
Trial 16	10	11.95	11.90	11.92	11.92	14	35.8
Trial 17	10	11.18	11.30	11.10	11.19	14	38.2
Trial 18	10	10.79	10.75	10.87	10.80	15	39.5

Table 15: Female6 data

Subject #	Female?	Height (m)	1.57	Resistance Level 1	10

Subject:	Female7	Height (m)	1.57	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	59.0	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.66	Resistance Level 3	20		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 1	10	12.96	12.90	13.08	12.98	14	32.9
Trial 2	10	13.60	13.68	13.48	13.59	14	31.4
Trial 3	20	16.51	16.61	16.48	16.53	19	51.7
Trial 4	15	17.00	16.90	17.01	16.97	18	37.8
Trial 5	15	17.21	17.15	17.08	17.15	19	37.4
Trial 6	20	20.38	20.41	20.31	20.37	22	42.0
Trial 7	15	16.91	16.99	16.84	16.91	20	37.9
Trial 8	20	20.46	20.52	20.58	20.52	23	41.6
Trial 9	10	14.22	14.08	14.17	14.16	16	30.2
Subject:	Female7	Height (m)	1.57	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	59.0	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.66	Resistance Level 3	20		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 10	10	15.42	15.37	15.57	15.45	15	27.6
Trial 11	15	18.89	18.88	18.72	18.83	21	34.0
Trial 12	10	17.55	17.65	17.55	17.58	18	24.3
Trial 13	15	20.73	20.79	20.69	20.74	23	30.9
Trial 14	20	22.94	22.85	22.81	22.87	28	37.4
Trial 15	10	18.14	18.15	18.24	18.18	19	23.5
Trial 16	20	22.95	23.12	23.10	23.06	27	37.1
Trial 17	15	20.71	20.69	20.80	20.73	24	30.9
Trial 18	20	22.02	22.08	21.91	22.00	27	38.8

Table 16: Female7 data

Subject:	Male1	Height (m)	1.70	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	78.0	Resistance Level 2	20		
PR 1-RM:	45	Arm Length (m)	0.74	Resistance Level 3	30		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	20	10.79	10.80	10.75	10.78	14	79.3
Trial 2	10	8.44	8.41	8.42	8.42	13	50.7
Trial 3	20	10.17	10.10	10.20	10.16	14	84.1
Trial 4	30	11.50	11.52	11.55	11.52	16	111.2
Trial 5	30	11.10	11.10	11.13	11.11	16	115.4
Trial 6	10	8.47	8.41	8.43	8.44	14	50.6
Trial 7	30	10.83	10.83	10.89	10.85	15	118.1
Trial 8	10	8.57	8.60	8.52	8.56	13	49.9
Trial 9	20	10.00	9.95	9.98	9.98	14	85.6
Subject:	Male1	Height (m)	1.70	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	78.0	Resistance Level 2	20		
PR 1-RM:	45	Arm Length (m)	0.74	Resistance Level 3	30		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	30	11.57	11.52	11.59	11.56	18	110.9
Trial 11	10	8.35	8.39	8.36	8.37	13	51.1
Trial 12	30	10.41	10.35	10.38	10.38	17	123.5
Trial 13	20	9.26	9.26	9.30	9.27	15	92.1
Trial 14	10	8.62	8.65	8.70	8.66	14	49.4
Trial 15	20	9.50	9.42	9.41	9.44	15	90.5
Trial 16	30	10.92	10.90	10.85	10.89	17	117.7
Trial 17	20	8.90	8.85	9.00	8.92	15	95.8
Trial 18	10	7.72	7.73	7.78	7.74	14	55.2

Table 17: Male1 data

Table 18: Male2 data

Subject:	Male2	Height (m)	1.75	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	76.2	Resistance Level 2	15		
PR 1-RM:	35	Arm Length (m)	0.73	Resistance Level 3	20		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 1	10	8.29	8.27	8.25	8.27	13	51.7
Trial 2	15	8.87	8.91	8.75	8.84	14	72.5
Trial 3	10	8.10	8.11	8.14	8.12	14	52.6
Trial 4	20	8.97	9.05	8.97	9.00	15	95.0
Trial 5	20	9.20	9.19	9.24	9.21	16	92.8
Trial 6	10	8.11	8.07	8.11	8.10	15	52.8
Trial 7	15	8.68	8.69	8.65	8.67	15	73.9
Trial 8	20	9.16	9.20	9.21	9.19	16	93.0
Trial 9	15	8.82	8.81	8.85	8.83	15	72.6
Subject:	Male2	Height (m)	1.75	Resistance Level 1	8.75		
Stroke (S or I):	I	Weight (kg)	76.2	Resistance Level 2	17.5		
PR 1-RM:	35	Arm Length (m)	0.73	Resistance Level 3	16.25		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 10	15	7.73	7.72	7.75	7.73	15	82.9
Trial 11	20	9.87	9.90	9.91	9.89	16	86.4
Trial 12	15	9.59	9.55	9.59	9.58	15	66.9
Trial 13	20	11.22	11.23	11.25	11.23	15	76.1
Trial 14	15	9.93	9.93	9.90	9.92	14	64.6
Trial 15	10	9.24	9.21	9.24	9.23	13	46.3
Trial 16	20	10.22	10.20	10.20	10.21	15	83.7
Trial 17	10	7.93	7.87	7.88	7.89	14	54.1
Trial 18	10	7.84	7.87	7.89	7.87	14	54.3

Subject:	Male3	Height (m)	1.78	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	75.7	Resistance Level 2	15		
PR 1-RM:	30	Arm Length (m)	0.79	Resistance Level 3	20		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 1	20	9.97	9.97	10.02	9.99	20	85.6
Trial 2	10	8.72	8.71	8.67	8.70	16	49.1
Trial 3	20	10.17	10.10	10.08	10.12	19	84.5
Trial 4	15	9.59	9.59	9.63	9.60	18	66.7
Trial 5	10	9.36	9.45	9.42	9.41	16	45.4
Trial 6	20	11.31	11.28	11.37	11.32	21	75.5
Trial 7	10	8.73	8.80	8.83	8.79	16	48.6
Trial 8	15	9.34	9.31	9.39	9.35	17	68.6
Trial 9	15	10.08	10.12	10.01	10.07	18	63.6

Subject:	Male3	Height (m)	1.78	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	75.7	Resistance Level 2	15		
PR 1-RM:	30	Arm Length (m)	0.79	Resistance Level 3	20		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 10	15	9.86	9.85	9.77	9.83	17	65.2
Trial 11	15	9.79	9.73	9.82	9.78	17	65.5
Trial 12	15	10.65	10.70	10.77	10.71	17	59.9
Trial 13	20	11.50	11.42	11.38	11.43	19	74.7
Trial 14	10	9.61	9.69	9.60	9.63	16	44.3
Trial 15	10	9.45	9.44	9.35	9.41	17	45.4
Trial 16	10	9.11	9.18	9.07	9.12	16	46.8
Trial 17	20	10.74	10.83	10.70	10.76	20	79.4
Trial 18	20	10.73	10.70	10.65	10.69	20	79.9

Table 19: Male3 data

Table 20: Male4 data

Subject:	Male4	Height (m)	1.78	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	73.5	Resistance Level 2	20		
PR 1-RM:	45	Arm Length (m)	0.81	Resistance Level 3	30		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	20	11.50	11.42	11.41	11.44	18	74.7
Trial 2	30	15.16	15.19	15.22	15.19	23	84.4
Trial 3	10	10.74	10.74	10.81	10.76	18	39.7
Trial 4	20	11.60	11.57	11.58	11.58	21	73.8
Trial 5	20	13.00	13.07	12.95	13.01	20	65.7
Trial 6	10	10.65	10.61	10.61	10.62	18	40.2
Trial 7	10	9.90	9.97	9.88	9.92	16	43.1
Trial 8	30	19.23	19.22	19.28	19.24	28	66.6
Trial 9	30	15.95	15.90	15.88	15.91	25	80.6

Subject:	Male4	Height (m)	1.78	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	73.5	Resistance Level 2	20		
PR 1-RM:	45	Arm Length (m)	0.81	Resistance Level 3	30		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	20	11.95	11.90	11.98	11.94	22	71.5
Trial 11	20	13.14	13.09	13.11	13.11	20	65.2
Trial 12	10	10.22	10.20	10.17	10.20	18	41.9
Trial 13	30	16.40	16.31	16.35	16.35	27	78.4
Trial 14	30	15.11	15.10	15.18	15.13	27	84.7
Trial 15	30	16.07	16.14	16.10	16.10	27	79.6
Trial 16	20	12.86	12.85	12.95	12.89	24	66.3
Trial 17	10	10.33	10.37	10.31	10.34	22	41.3
Trial 18	10	10.44	10.36	10.45	10.42	21	41.0

Table 21: Male5 data

Subject:	Male5	Height (m)	1.85	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	77.6	Resistance Level 2	15		
PR 1-RM:	20	Arm Length (m)	0.81	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	15	7.80	7.90	7.93	7.88	16	81.4
Trial 2	10	7.86	7.90	7.81	7.86	15	54.4
Trial 3	20	8.25	8.20	8.18	8.21	16	104.1
Trial 4	15	8.93	8.95	9.01	8.96	17	71.5
Trial 5	10	8.35	8.20	8.23	8.26	15	51.7
Trial 6	15	9.26	9.39	9.23	9.29	17	69.0
Trial 7	20	10.01	10.07	9.95	10.01	18	85.4
Trial 8	20	10.40	10.26	10.31	10.32	18	82.8
Trial 9	10	8.30	8.36	8.41	8.36	15	51.1

Subject:	Male5	Height (m)	1.85	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	77.6	Resistance Level 2	15		
PR 1-RM:	20	Arm Length (m)	0.81	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	15	10.10	10.01	10.23	10.11	15	63.4
Trial 11	10	9.39	9.35	9.30	9.35	14	45.7
Trial 12	20	10.82	10.80	10.94	10.85	17	78.7
Trial 13	20	11.22	11.23	11.08	11.18	17	76.5
Trial 14	10	9.58	9.66	9.72	9.65	14	44.3
Trial 15	15	10.25	10.14	10.22	10.20	16	62.8
Trial 16	10	9.54	9.37	9.52	9.48	15	45.1
Trial 17	20	10.82	10.70	10.70	10.74	18	79.6
Trial 18	15	10.54	10.66	10.68	10.63	15	60.3

Subject:	Male6	Height (m)	1.73	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	56.6	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.65	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	10	8.82	8.90	8.98	8.90	16	48.0
Trial 2	15	9.93	9.85	10.02	9.93	17	64.5
Trial 3	10	9.39	9.38	9.49	9.42	16	45.4
Trial 4	15	11.12	11.01	11.60	11.24	16	57.0
Trial 5	10	10.36	10.22	10.29	10.29	15	41.5
Trial 6	15	10.74	10.90	10.71	10.78	18	59.4
Trial 7	20	12.71	12.60	12.65	12.65	20	67.5
Trial 8	20	12.66	12.70	12.52	12.63	21	67.7
Trial 9	20	11.60	11.65	11.73	11.66	20	73.3

Subject:	Male 6	Height (m)	1.73	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	56.6	Resistance Level 2	15		
PR 1-RM:	25	Arm Length (m)	0.65	Resistance Level 3	20		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	15	9.43	9.43	9.33	9.40	16	68.2
Trial 11	20	11.42	11.52	11.37	11.44	18	74.7
Trial 12	10	10.22	10.25	10.37	10.28	17	41.6
Trial 13	20	11.36	11.30	11.31	11.32	21	75.5
Trial 14	15	11.13	11.01	11.20	11.11	18	57.7
Trial 15	10	10.30	10.29	10.42	10.34	17	41.3
Trial 16	15	10.65	10.81	10.73	10.73	18	59.7
Trial 17	10	10.50	10.58	10.55	10.54	18	40.5
Trial 18	20	12.70	12.75	12.90	12.78	21	66.8

Table 22: Male6 data

Subject:	Male7	Height (m)	1.83	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	74.5	Resistance Level 2	20		
PR 1-RM:	40	Arm Length (m)	0.80	Resistance Level 3	30		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 1	10	6.60	6.72	6.75	6.69	13	63.9
Trial 2	20	8.86	8.80	8.94	8.87	14	96.4
Trial 3	20	9.30	9.15	9.13	9.19	15	92.9
Trial 4	20	9.36	9.46	9.23	9.35	14	91.4
Trial 5	30	11.52	11.45	11.35	11.44	15	112.0
Trial 6	10	7.86	7.99	7.89	7.91	13	54.0
Trial 7	30	10.52	10.59	10.37	10.49	15	122.1
Trial 8	10	8.29	8.20	8.13	8.21	13	52.1
Trial 9	30	10.51	10.69	10.45	10.55	16	121.5
Subject:	Male 6	Height (m)	1.83	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	74.5	Resistance Level 2	20		
PR 1-RM:	40	Arm Length (m)	0.80	Resistance Level 3	30		
Power Rack	Weight (lbs)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Avg Time (s)	Stroke Count	Pavg (W)
Trial 10	30	11.51	11.50	11.69	11.57	16	110.8
Trial 11	20	9.64	9.78	9.58	9.67	14	88.4
Trial 12	20	10.24	10.14	10.10	10.16	14	84.1
Trial 13	10	8.81	8.96	9.02	8.93	12	47.8
Trial 14	10	8.82	8.68	8.75	8.75	13	48.8
Trial 15	10	9.07	9.15	8.95	9.06	12	47.2
Trial 16	20	10.22	10.10	10.35	10.22	14	83.6
Trial 17	30	12.09	12.20	12.25	12.18	16	105.2
Trial 18	30	12.16	12.30	12.15	12.20	16	105.0

Table 23: Male7 data

Subject:	Male8	Height (m)	1.75	Resistance Level 1	10		
Stroke (S or I):	I	Weight (kg)	68.0	Resistance Level 2	20		
PR 1-RM:	40	Arm Length (m)	0.76	Resistance Level 3	30		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 1	30	9.08	9.17	9.01	9.09	17	141.1
Trial 2	10	7.29	7.39	7.25	7.31	14	58.4
Trial 3	20	8.30	8.45	8.37	8.37	15	102.0
Trial 4	10	7.92	7.85	7.76	7.84	14	54.5
Trial 5	30	9.47	9.40	9.35	9.41	17	136.3
Trial 6	20	8.15	8.27	8.08	8.17	15	104.6
Trial 7	20	8.65	8.61	8.77	8.68	15	98.5
Trial 8	10	7.55	7.37	7.48	7.47	14	57.2
Trial 9	30	9.70	9.81	9.85	9.79	17	131.0
Subject:	Male8	Height (m)	1.75	Resistance Level 1	10		
Stroke (S or I):	S	Weight (kg)	68.0	Resistance Level 2	20		
PR 1-RM:	40	Arm Length (m)	0.76	Resistance Level 3	30		
Power Rack	**Weight (lbs)**	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Avg Time (s)**	**Stroke Count**	**Pavg (W)**
Trial 10	30	10.06	10.07	10.19	10.11	16	126.8
Trial 11	10	7.60	7.69	7.51	7.60	12	56.2
Trial 12	30	9.34	9.15	9.20	9.23	15	138.9
Trial 13	20	8.84	8.95	8.99	8.93	14	95.7
Trial 14	10	7.78	7.78	7.88	7.81	13	54.7
Trial 15	20	8.49	8.31	8.37	8.39	14	101.8
Trial 16	30	10.21	10.15	10.36	10.24	17	125.2
Trial 17	10	8.03	8.00	7.91	7.98	14	53.5
Trial 18	20	8.99	8.88	9.07	8.98	15	95.2

Table 24: Male8 data

APPENDIX F -- Stroke Analysis

Notes: A denoting of I/S indicates the stroke style could not be determined.

A denoting of I* or S* means that the trial was not recorded clearly.

Subject:	Male 1		
Trial	**Described Stroke**	**Resistance Level**	**Average Power**
1	S	20	79.3
2	S	10	50.7
3	S	20	84.1
4	S	30	111.2
5	S	30	115.4
6	S	10	50.6
7	S	30	118.1
8	S	10	49.9
9	I	20	85.6
10	I	30	110.9
11	I	10	51.1
12	I	30	123.5
13	I	20	92.1
14	I	10	49.4
15	S*	20	90.5
16	I	30	117.7
17	S*	20	95.8
18	I	10	55.2
Notes:	With the S-pull, subject takes a few strokes to get going...also shows some pronounced up-and-down movement with the legs as he swims. With the I-pull, the hand tends to go deeper then on the S. Can only get data from the first couple of pulls due to turbulence in the water		

Table 25: Stroke analysis, Male1

Subject: Male 2			
Trial	**Described Stroke**	**Resistance Level**	**Average Power**
1	S	10	51.7
2	S	15	72.5
3	S	10	52.6
4	S	20	95.0
5	S	20	92.8
6	S	10	52.8
7	S	15	73.9
8	S	20	93.0
9	S	15	72.6
10	I/S	15	82.9
11	I/S	20	86.4
12	I/S	15	66.9
13	I/S	20	76.1
14	I/S	15	64.6
15	I/S	10	46.3
16	I/S	20	83.7
17	I/S	10	54.1
18	I/S	10	54.3
Notes:	Legs drop a lot, some fishtailing but this is mostly due to body rotation. There is no turbulence in the water. On the S-pull there is a lot of elbow flexion during the in-sweep. There is some elbow flexion with the I-pull but not nearly to the degree as with the S-pull. The I-pull does have some S-shape characteristics to it.		

Table 26: Stroke analysis, Male2

Subject: Male 3			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	I	20	85.6
2	I	10	49.1
3	I	20	84.5
4	I	15	66.7
5	I	10	45.4
6	I	20	75.5
7	I	10	48.6
8	I	15	68.6
9	I	15	63.6
10	S	15	65.2
11	S	15	65.5
12	S	15	59.9
13	S	20	74.7
14	S	10	44.3
15	S	10	45.4
16	S	10	46.8
17	S	20	79.4
18	S	20	79.9
Notes:	There is a little elbow flexion on the I, but it is minimal. The hand is laterally wide of the body during the I-Pull. The feet drop with the I-Pull and there is very little lateral movement of the legs. The subject had a hard time swimming straight during the S-Pull. There is fishtailing of the legs/lower body during the S-Pull. A distinct catch and elbow flexion are visible during the S-Pull with the catch moving real wide of the body. After the catch, one can see movement of the arm/hand back toward the body		

Table 27: Stroke analysis, Male3

Subject: Male 4			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	I	20	74.7
2	I	30	84.4
3	I	10	39.7
4	I	20	73.8
5	I/S	20	65.7
6	I	10	40.2
7	I	10	43.1
8	I	30	66.6
9	I	30	80.6
10	S	20	71.5
11	S	20	65.2
12	S	10	41.9
13	S	30	78.4
14	S	30	84.7
15	S	30	79.6
16	S	20	66.3
17	S	10	41.3
18	S	10	41.0
Notes:	The feet sink during both sets of trials and there is a butterfly movement with them. The I-pull goes wide of the body. There is a lot more turbulence in the water during the S-Pull. There is evident elbow flexion during the catch and as the pull comes toward the midline of the body.		

Table 28: Stroke analysis, Male4

Subject: Male 5			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	I	15	81.4
2	I	10	54.4
3	I	20	104.1
4	I	15	71.5
5	I	10	51.7
6	I	15	69.0
7	I	20	85.4
8	I	20	82.8
9	I	10	51.1
10	S	15	63.4
11	S	10	45.7
12	S	20	78.7
13	S	20	76.5
14	S	10	44.3
15	S	15	62.8
16	S	10	45.1
17	S	20	79.6
18	S	15	60.3
Notes:	The I-Pull creates turbulence and the pull goes under the body but it is a straight pull (think diagonal). The legs are dropping a bit but not as much as with other subjects. There is elbow flextion during both pulls but there is a greater amount with the S-Pull One can see an outsweep at the end of the S-Pull as the hand exits the water.		

Table 29: Stroke analysis, Male5

Subject: Male 6			
Trial	Described Stroke	Resistance Level (lbs)	Average Power (W)
1	I	10	48.0
2	I	15	64.5
3	I	10	45.4
4	I	15	57.0
5	I	10	41.5
6	I	15	59.4
7	I	20	67.5
8	I	20	67.7
9	I	20	73.3
10	S	15	68.2
11	S	20	74.7
12	S	10	41.6
13	S	20	75.5
14	S	15	57.7
15	S	10	41.3
16	S	15	59.7
17	S	10	40.5
18	S	20	66.8
Notes:	The legs drop a lot during the I-Pull and the subject tries to do some butterfly kicks to get the legs to the surface. There is also some lateral movement of the legs during a few of the trials. The I-Pull is wide of the body and stays there. The S-Pull has a visible insweep toward the body. The S-Pull has a tendencey to create more eddies/turbulence in the water due to the back-and-forth nature of the pull. There is still a little bit of the butterfly kicks with the S-Pull		

Table 30: Stroke analysis, Male6

Subject: Male 7			
Trial	Described Stroke	Resistance Level (lbs)	Average Power (W)
1	I	10	63.9
2	I	20	96.4
3	I	20	92.9
4	I	20	91.4
5	S*	30	112.0
6	I	10	54.0
7	I	30	122.1
8	S*	10	52.1
9	I	30	121.5
10	S	30	110.8
11	S	20	88.4
12	S	20	84.1
13	S	10	47.8
14	S	10	48.8
15	S	10	47.2
16	S	20	83.6
17	S	30	105.2
18	S	30	105.0
Notes:	The subject does a good job of differentiating between the two stroke styles. The legs are dropping and there is a little vertical movement with them. The I-Stroke is a bit inconsistent and two of the trials were more curvilinear. The S-Stroke exhibits a good amount of elbow flexion and on the video one can see the out-in-out characteristics of the stroke.		

Table 31: Stroke analysis, Male7

Subject: Male 8			
Trial	Described Stroke	Resistance Level (lbs)	Average Power (W)
1	I	30	141.1
2	I	10	58.4
3	I	20	102.0
4	I	10	54.5
5	I	30	136.3
6	I	20	104.6
7	I	20	98.5
8	I	10	57.2
9	I	30	131.0
10	S	30	126.8
11	S	10	56.2
12	S	30	138.9
13	S	20	95.7
14	S	10	54.7
15	S	20	101.8
16	S	30	125.2
17	S	10	53.5
18	S	20	95.2
Notes:	The I-Stroke is very straight and this seems to be the more natural of the stroke of this subject. There pull path is wide of the body and the arm/hand remain straight throughout. The S-Pull creates more turbulence as the hand comes under the body and then back away. There is more elbow flexion during the catch of the S-Stroke while with the I-Stroke the arm has minimal elbow flexion		

Table 32: Stroke analysis, Male8

Subject: Female 1			
Trial	Described Stroke	Resistance Level (lbs)	Average Power (W)
1	S	20	66.7
2	S	10	42.3
3	S	20	68.7
4	S	10	43.5
5	S	15	58.9
6	S	15	56.8
7	S	20	65.4
8	S	10	43.3
9	I	15	54.8
10	I	15	59.3
11	I	10	43.1
12	I/S*	15	56.1
13	I	20	69.3
14	I/S*	15	62.7
15	I	10	43.3
16	I	20	67.9
17	S*	20	69.6
18	I	10	43.5
Notes:	Subject had some equipment issues and and it took 3 trials before there was a good trial. The S-Pull comes out and back in toward the body and then underneath. There is not so much out-movement with the I-Pull, it is straighter and still comes under the body. There is variance between the trials - the strokes are not consistent		

Table 33: Stroke analysis, Female1

Subject: Female 2			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	S	15	63.1
2	S	10	43.8
3	S	20	71.6
4	S	15	59.2
5	S	10	42.7
6	S	10	41.2
7	S	20	67.7
8	S	15	53.2
9	S	20	59.1
10	I	15	57.6
11	I	20	62.7
12	I	20	60.7
13	I	20	55.7
14	I	10	39.3
15	I/S*	10	39.2
16	I	15	52.1
17	I	10	38.9
18	I	15	52.6
Notes:	There is some extra lateral and vertical movement with the legs during all trials, kind of like a butterfly kick. There is elbow flexion during the S-Pull. There is more water turbulence with the I-Pull and it is more of a diagonal pull from out-to-in. The hand stays wide of the body and doesn't come underneath.		

Table 34: Stroke analysis, Female2

Subject: Female 3			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	S	20	54.6
2	S	15	48.5
3	S	10	35.6
4	S	15	46.2
5	S	10	36.4
6	S	15	42.6
7	S	20	46.7
8	S	10	32.3
9	S	20	43.2
10	S	10	36.2
11	I	10	34.8
12	I/S*	15	42.0
13	I/S*	15	41.1
14	I	15	40.5
15	I/S*	20	53.0
16	S	20	42.6
17	S	20	43.8
18	I/S*	10	34.0
Notes:	The subject has a hard time maintaining a straight path pull with the I-Stroke and there is more variability with this pull than with the S-Stroke. The hand and arm come under the body during the catch of the S-Stroke and stay wide of the body during the I-Stroke. The legs like to drop and there is lateral movement with the legs that affects body position.		

Table 35: Stroke analysis, Female3

Subject: Female 4			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	S	10	47.7
2	S	20	86.7
3	S	20	75.2
4	S	15	59.4
5	S	20	74.7
6	S	10	41.1
7	S	15	56.8
8	S	15	54.9
9	S	10	41.3
10	I	10	45.2
11	I	10	41.2
12	I	15	61.8
13	I	20	75.4
14	I	20	70.5
15	I	20	69.9
16	I	10	43.7
17	I	15	58.2
18	I	15	56.3
Notes:	The arm enters wide with the S-Stroke and has a nice catch, although the arm does not travel under the body like some of the other subjects. The legs are pretty elevated with some minimal lateral movements. The arm stays wide of the body during the I-pull and there is less elbow flexion. The I-Stroke seems more natural for the subject		

Table 36: Stroke analysis, Female4

Subject: Female 5			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	S	15	38.8
2	S	15	40.8
3	S	10	29.7
4	S	20	45.1
5	S	10	28.6
6	S	15	40.3
7	S	20	43.9
8	S	10	30.2
9	S	20	45.0
10	I	20	58.7
11	I	10	36.5
12	I	20	49.3
13	I	10	34.1
14	I	15	49.3
15	I	10	35.4
16	I	20	53.8
17	I	15	48.3
18	I	15	47.0
Notes:	The S-Stroke is more of a wide pull and the arm doesn't come under the body until the middle of the pull. As the hand moves under the body, there is a lot of elbow flexion. The legs are pretty still and just rotate with the body. There is elbow flexion with the I-pull but the arm does not travel under the body - it stays laterally to the state.		

Table 37: Stroke analysis, Female5

Subject: Female 6			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	I	15	64.8
2	I	10	44.3
3	I	10	41.4
4	I	20	72.7
5	I	20	68.6
6	I	15	57.5
7	I	15	53.0
8	I	20	63.0
9	I	10	39.1
10	S	15	45.1
11	S	20	54.3
12	S	20	54.7
13	S*	15	51.7
14	S*	20	58.3
15	S*	15	47.2
16	S*	10	35.8
17	S*	10	38.2
18	S*	10	39.5
Notes:	The arm is very straight during the I-Pull, maybe the best one yet! It is a wide pull and therere is minimal elbow flexion. The legs stay pretty elevated and the only movement is with the natural body rotations. The S-Pull has substantially more elbow flexion - the arm enters wide and and then sweeps back toward the body. There were some camera issues and only the first 3 of the S-Pull trials were able to be recorded.		

Table 38: Stroke analysis, Female6

Subject: Female 7			
Trial	**Described Stroke**	**Resistance Level (lbs)**	**Average Power (W)**
1	S	10	32.9
2	S	10	31.4
3	S	20	51.7
4	S	15	37.8
5	S	15	37.4
6	S	20	42.0
7	S*	15	37.9
8	S*	20	41.6
9	S*	10	30.2
10	I	10	27.6
11	I	15	34.0
12	I	10	24.3
13	I*	15	30.9
14	I*	20	37.4
15	I*	10	23.5
16	I*	20	37.1
17	I*	15	30.9
18	I*	20	38.8
Notes:	The S-Stroke enters wide and then sweeps back in toward the body. There characteristic elbow flexion during the catch as the amr and hand sweep back toward the body. The feet and legs stay in an elevated position and there is little extra movement with them. The camera wasn't able to record the last three S-Stroke trials and was only able to get the first three I-Stroke trials. From the ones that were recorded, there is a visible difference between the two strokes. There is still elbow flexion with the I-Stroke but the arm and hand stay wide of the body and do not sweep back toward the middle		

Table 39: Stroke analysis, Female7

APPENDIX G – I-Stroke and S-Stroke Scatter Plots of Power Output

*Each participant should have six data points: three each for the I-Stroke and S-Stroke. Participants with fewer than three data points indicate that the stroke style was incorrect and thus left out of the calculations

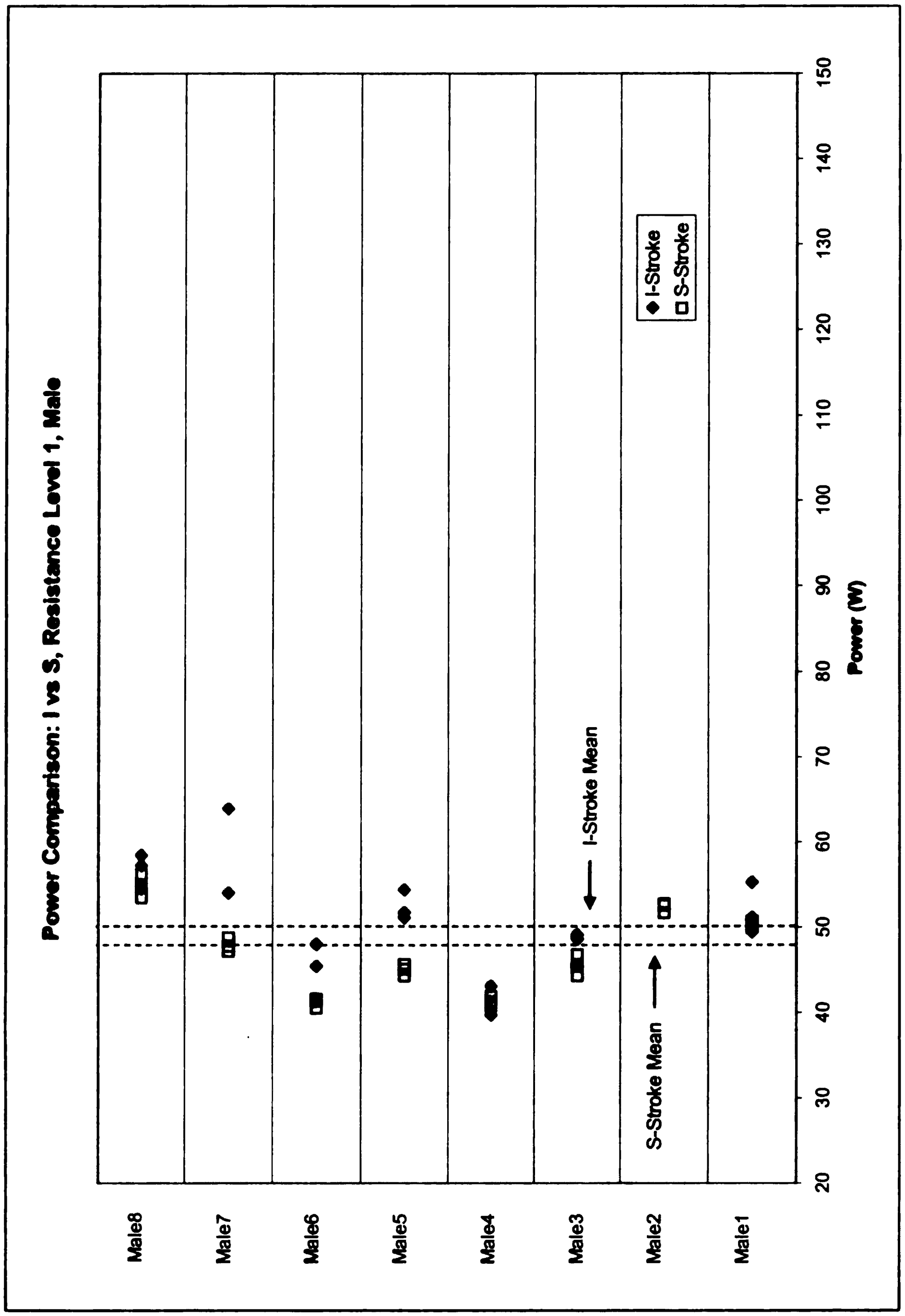

Figure 12: Power comparison, males, I-Stroke vs. S-Stroke, resistance level 1

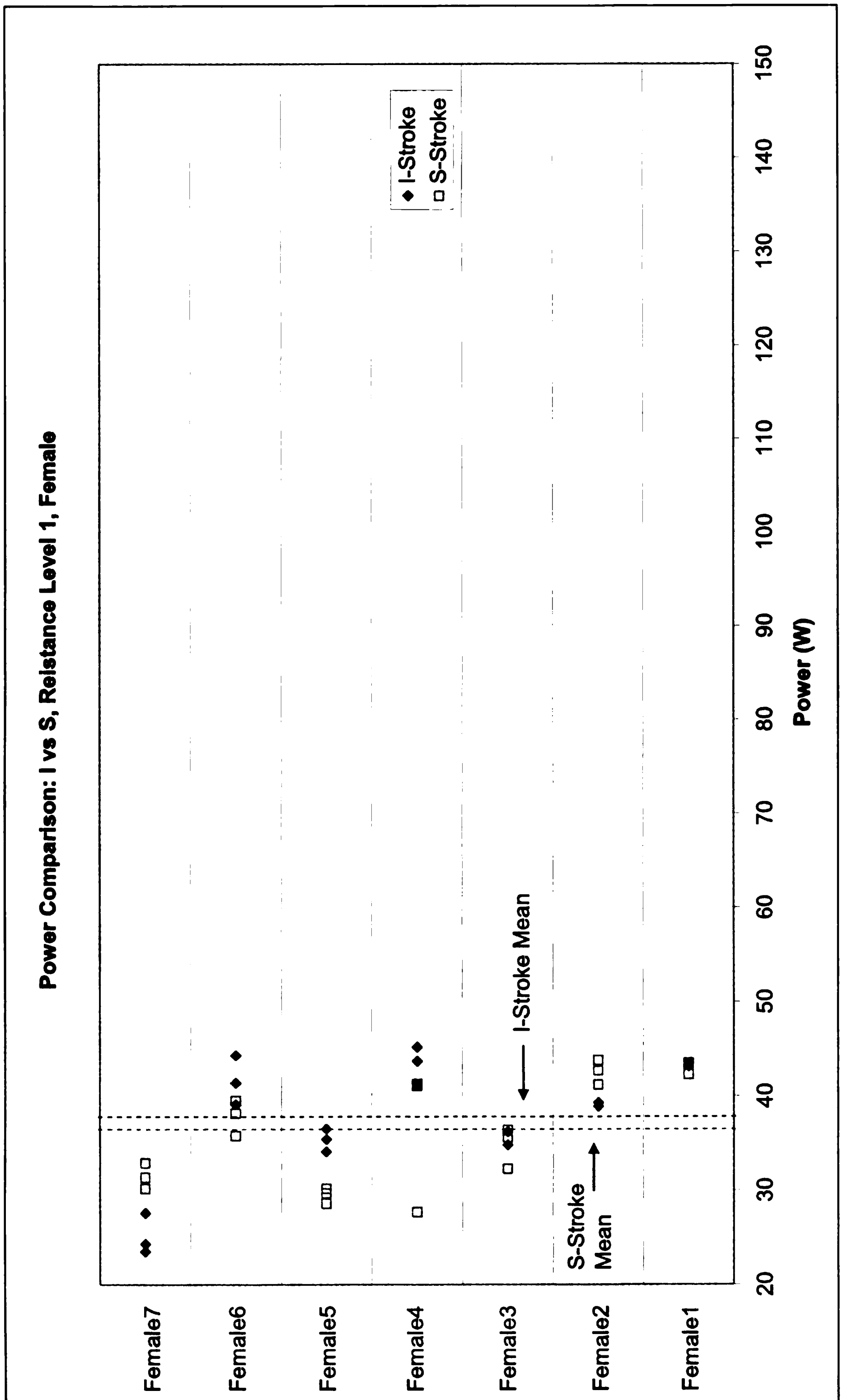

Figure 13: Power comparison, females, I-Stroke vs S-Stroke, resistance level 1

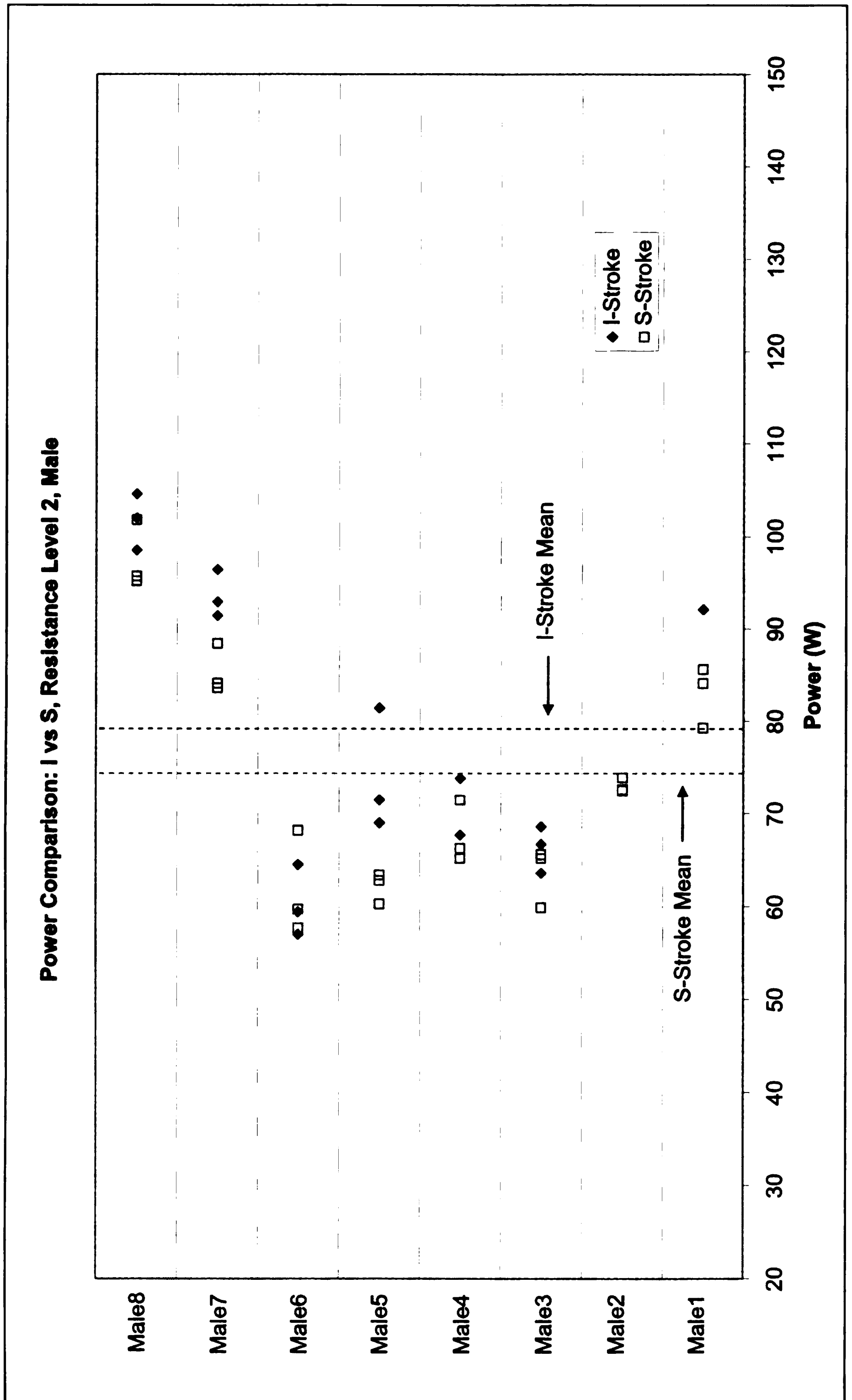

Figure 14: Power comparison, males, I-Stroke vs S-Stroke, resistance level 2

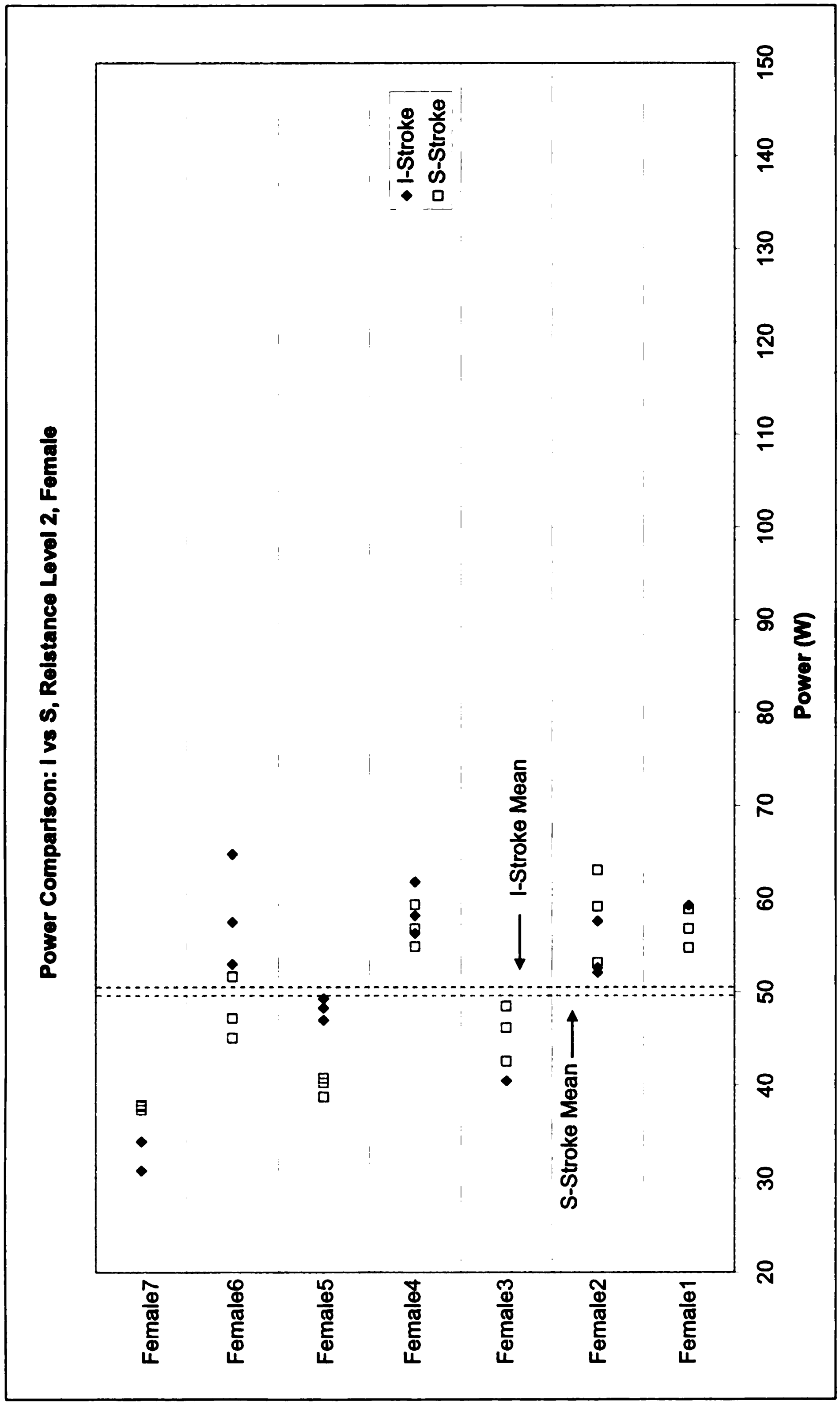

Figure 15: Power comparison, females, I-Stroke vs S-Stroke, resistance level 2

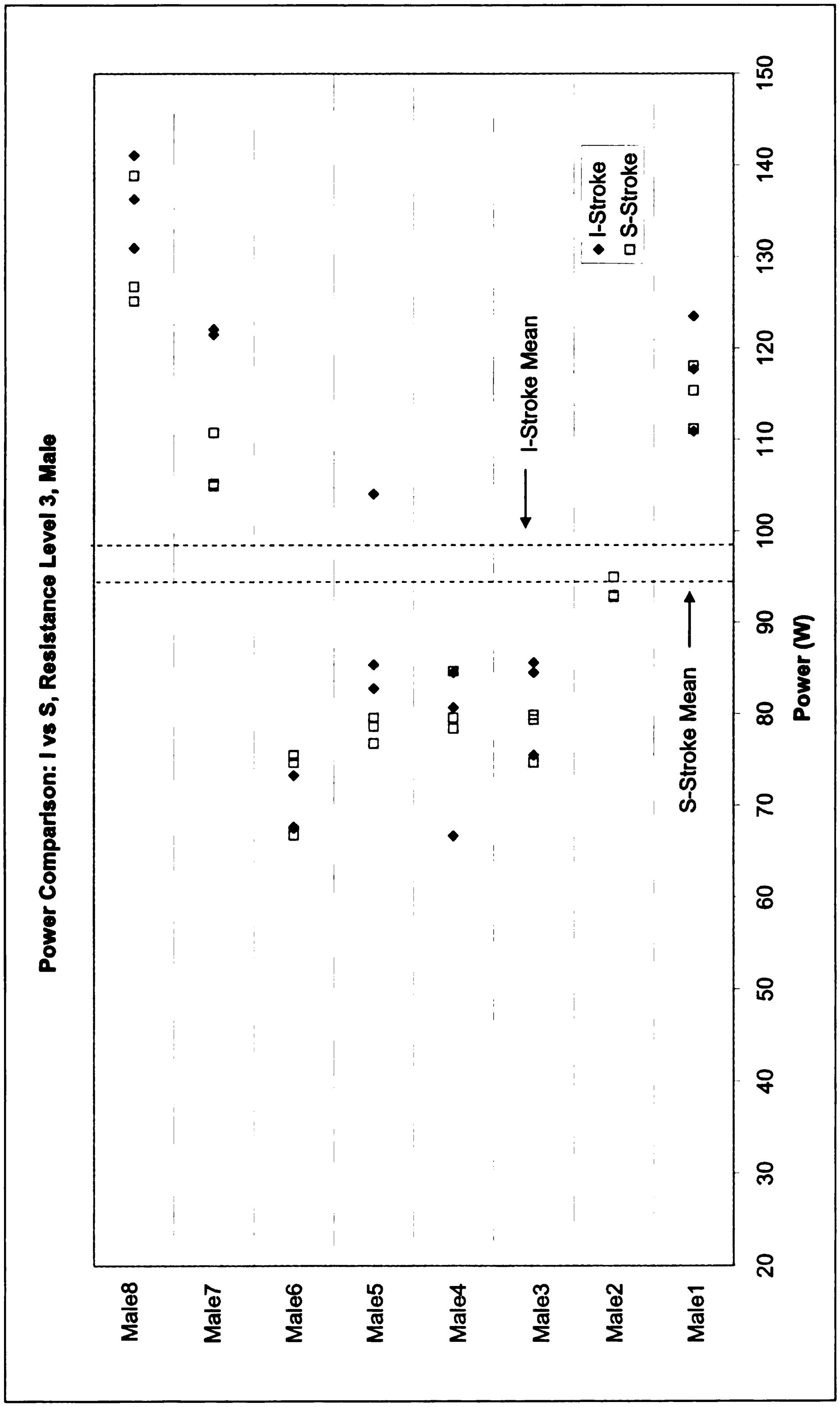

Figure 16: Power comparison, males, I-Stroke vs S-Stroke, resistance level 3

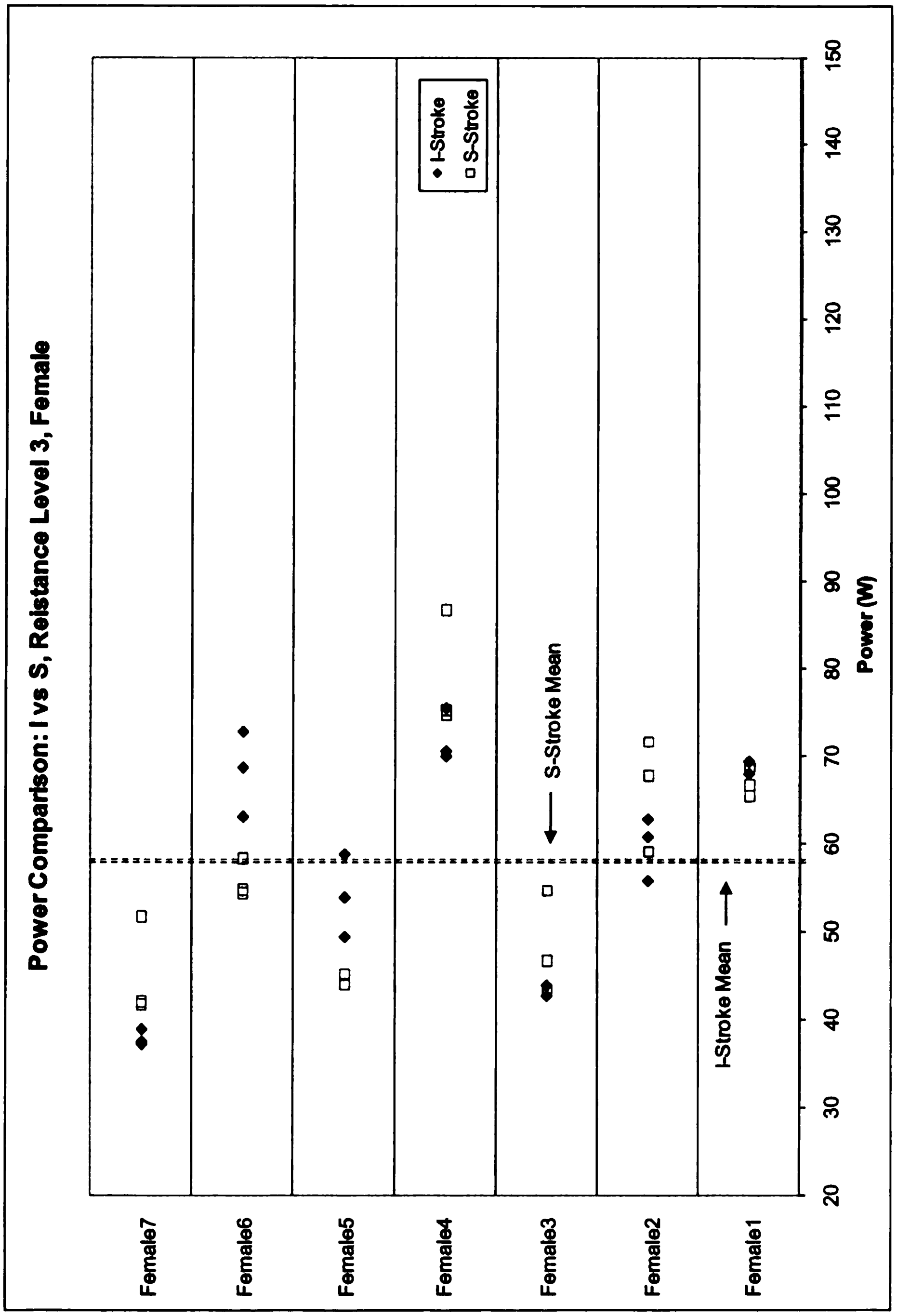

Figure 17: Power comparison, females, I-Stroke vs S-Stroke, resistance level 3

APPENDIX H -- t-test Results

Reistance Level	Level 1		Level 2		Level 3	
Stroke Type	*I*	*S*	*I*	*S*	*I*	*S*
Mean	43.94	42.05	64.81	61.80	78.24	76.25
Variance	83.95	48.53	416.08	299.05	861.12	674.92
Observations	14.00	14.00	14.00	14.00	14.00	14.00
Pearson Correlation	0.89		0.97		0.97	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	13.00		13.00		13.00	
t Stat	1.62		2.00		1.05	
P(T<=t) one-tail	0.06		0.03		0.16	
t Critical one-tail	1.77		1.77		1.77	
P(T<=t) two-tail	0.13		0.07		0.31	
t Critical two-tail	2.16		2.16		2.16	

Table 40: Dependent t-test – I-Stroke versus S-Stroke, entire population

Reistance Level	Level 1		Level 2		Level 3	
Stroke Type	*I*	*S*	*I*	*S*	*I*	*S*
Mean	50.53	46.59	80.33	74.49	99.26	94.54
Variance	40.77	24.07	240.96	199.96	655.86	510.55
Observations	7.00	7.00	7.00	7.00	7.00	7.00
Pearson Correlation	0.78		0.96		0.97	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	6.00		6.00		6.00	
t Stat	2.62		3.45		1.78	
P(T<=t) one-tail	0.02		0.01		0.06	
t Critical one-tail	1.94		1.94		1.94	
P(T<=t) two-tail	0.04		0.01		0.12	
t Critical two-tail	2.45		2.45		2.45	

Table 41: Dependent t-test – I-Stroke versus S-Stroke, males

Reistance Level	Level 1		Level 2		Level 3	
Stroke Type	*I*	*S*	*I*	*S*	*I*	*S*
Mean	37.34	37.51	49.30	49.11	57.21	57.96
Variance	39.71	33.07	98.94	72.49	178.80	170.97
Observations	7.00	7.00	7.00	7.00	7.00	7.00
Pearson Correlation	0.80		0.83		0.88	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	6.00		6.00		6.00	
t Stat	-0.12		0.09		-0.30	
P(T<=t) one-tail	0.46		0.47		0.39	
t Critical one-tail	1.94		1.94		1.94	
P(T<=t) two-tail	0.91		0.93		0.77	
t Critical two-tail	2.45		2.45		2.45	

Table 42: Dependent t-test – I-Stroke versus S-Stroke, females

I-Stroke	Resistance Level 1		Resistance Level 2		Resistance Level 3	
	Freestylers	*Non-Freestylers*	*Freestylers*	*Non-Freestylers*	*Freestylers*	*Non-Freestylers*
Mean	47.66	37.24	72.89	50.28	88.88	59.08
Variance	64.18	57.32	408.74	124.04	937.94	209.26
Observations	9.00	5.00	9.00	5.00	9.00	5.00
Pooled Variance	61.89		313.84		695.05	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	12.00		12.00		12.00	
t Stat	2.37		2.29		2.03	
P(T<=t) one-tail	0.02		0.02		0.03	
t Critical one-tail	1.78		1.78		1.78	
P(T<=t) two-tail	0.04		0.04		0.07	
t Critical two-tail	2.18		2.18		2.18	

S-Stroke	Resistance Level 1		Resistance Level 2		Resistance Level 3	
	Freestylers	*Non-Freestylers*	*Freestylers*	*Non-Freestylers*	*Freestylers*	*Non-Freestylers*
Mean	44.30	40.40	68.36	53.83	85.09	65.88
Variance	39.19	72.52	298.24	171.92	738.45	363.88
Observations	9.00	6.00	9.00	6.00	9.00	6.00
Pooled Variance	52.01		249.66		594.38	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	13.00		13.00		13.00	
t Stat	1.03		1.74		1.49	
P(T<=t) one-tail	0.16		0.05		0.08	
t Critical one-tail	1.77		1.77		1.77	
P(T<=t) two-tail	0.32		0.10		0.16	
t Critical two-tail	2.16		2.16		2.16	

Table 43: Independent t-test -- Freestylers versus non-freestylers, entire population

I-Stroke	Resistance Level 1		Resistance Level 2		Resistance Level 3	
	Sprinters	*Non-Sprinters*	*Sprinters*	*Non-Sprinters*	*Sprinters*	*Non-Sprinters*
Mean	46.48	42.03	68.10	62.35	83.17	74.54
Variance	50.31	110.25	332.49	519.04	815.39	980.33
Observations	6.00	8.00	6.00	8.00	6.00	8.00
Pooled Variance	85.27		441.31		911.60	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	12.00		12.00		12.00	
t Stat	0.89		0.51		0.53	
P(T<=t) one-tail	0.19		0.31		0.30	
t Critical one-tail	1.78		1.78		1.78	
P(T<=t) two-tail	0.39		0.62		0.61	
t Critical two-tail	2.18		2.18		2.18	
S-Stroke	Resistance Level 1		Resistance Level 2		Resistance Level 3	
	Sprinters	*Non-Sprinters*	*Sprinters*	*Non-Sprinters*	*Sprinters*	*Non-Sprinters*
Mean	45.87	40.00	65.67	59.81	81.30	74.00
Variance	34.56	56.41	255.32	334.96	610.04	742.24
Observations	7.00	8.00	7.00	8.00	7.00	8.00
Pooled Variance	46.32		298.20		681.22	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	13.00		13.00		13.00	
t Stat	1.67		0.66		0.54	
P(T<=t) one-tail	0.06		0.26		0.30	
t Critical one-tail	1.77		1.77		1.77	
P(T<=t) two-tail	0.12		0.52		0.60	
t Critical two-tail	2.16		2.16		2.16	

Table 44: Independent t-test – Sprinters versus non-sprinters, entire population

I-Stroke	Resistance Level 1		Resistance Level 2		Resistance Level 3	
	Males	*Females*	*Males*	*Females*	*Males*	*Females*
Mean	50.53	37.34	80.33	49.30	99.26	57.21
Variance	40.77	39.71	240.96	98.94	655.86	178.80
Observations	7.00	7.00	7.00	7.00	7.00	7.00
Pooled Variance	40.24		169.95		417.33	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	12.00		12.00		12.00	
t Stat	3.89		4.45		3.85	
P(T<=t) one-tail	0.00		0.00		0.00	
t Critical one-tail	1.78		1.78		1.78	
P(T<=t) two-tail	0.00		0.00		0.00	
t Critical two-tail	2.18		2.18		2.18	
S-Stroke	Resistance Level 1		Resistance Level 2		Resistance Level 3	
	Males	*Females*	*Males*	*Females*	*Males*	*Females*
Mean	47.31	37.51	74.30	49.11	94.43	57.96
Variance	24.86	33.07	171.67	72.49	437.73	170.97
Observations	8.00	7.00	8.00	7.00	8.00	7.00
Pooled Variance	28.65		125.89		314.61	
Hypothesized Mean Difference	0.00		0.00		0.00	
df	13.00		13.00		13.00	
t Stat	3.54		4.34		3.97	
P(T<=t) one-tail	0.00		0.00		0.00	
t Critical one-tail	1.77		1.77		1.77	
P(T<=t) two-tail	0.00		0.00		0.00	
t Critical two-tail	2.16		2.16		2.16	

Table 45: Independent t-test – Male versus female, entire population

APPENDIX I – ANOVA Charts

Note: All charts were calculated using SPSS statistical software

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
StrokeType	Sphericity Assumed	.034	1	.034	.000	.993	.000	.050
	Greenhouse-Geisser	.034	1.000	.034	.000	.993	.000	.050
	Huynh-Feldt	.034	1.000	.034	.000	.993	.000	.050
	Lower-bound	.034	1.000	.034	.000	.993	.000	.050
Error(StrokeType)	Sphericity Assumed	6050.917	13	465.455				
	Greenhouse-Geisser	6050.917	13.000	465.455				
	Huynh-Feldt	6050.917	13.000	465.455				
	Lower-bound	6050.917	13.000	465.455				
PowerLevel	Sphericity Assumed	17907.540	2	8953.770	60.390	.000	120.780	1.000
	Greenhouse-Geisser	17907.540	1.038	17246.578	60.390	.000	62.704	1.000
	Huynh-Feldt	17907.540	1.048	17086.389	60.390	.000	63.292	1.000
	Lower-bound	17907.540	1.000	17907.540	60.390	.000	60.390	1.000
Error(PowerLevel)	Sphericity Assumed	3854.907	26	148.266				
	Greenhouse-Geisser	3854.907	13.498	285.586				
	Huynh-Feldt	3854.907	13.625	282.934				
	Lower-bound	3854.907	13.000	296.531				
StrokeType * PowerLevel	Sphericity Assumed	6.835	2	3.418	.066	.936	.132	.059
	Greenhouse-Geisser	6.835	1.228	5.564	.066	.849	.081	.057
	Huynh-Feldt	6.835	1.291	5.294	.066	.859	.085	.057
	Lower-bound	6.835	1.000	6.835	.066	.801	.066	.057
Error(StrokeType*PowerLevel)	Sphericity Assumed	1344.958	26	51.729				
	Greenhouse-Geisser	1344.958	15.970	84.218				
	Huynh-Feldt	1344.958	16.784	80.131				
	Lower-bound	1344.958	13.000	103.458				

a. Computed using alpha = .05

Table 46: Repeated measures ANOVA for entire population

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
StrokeType	Sphericity Assumed	649.787	1	649.787	2.238	.185	2.238	.244
	Greenhouse-Geisser	649.787	1.000	649.787	2.238	.185	2.238	.244
	Huynh-Feldt	649.787	1.000	649.787	2.238	.185	2.238	.244
	Lower-bound	649.787	1.000	649.787	2.238	.185	2.238	.244
Error(StrokeType)	Sphericity Assumed	1741.947	6	290.324				
	Greenhouse-Geisser	1741.947	6.000	290.324				
	Huynh-Feldt	1741.947	6.000	290.324				
	Lower-bound	1741.947	6.000	290.324				
PowerLevel	Sphericity Assumed	14917.090	2	7458.545	59.564	.000	119.128	1.000
	Greenhouse-Geisser	14917.090	1.071	13924.940	59.564	.000	63.808	1.000
	Huynh-Feldt	14917.090	1.116	13370.789	59.564	.000	66.452	1.000
	Lower-bound	14917.090	1.000	14917.090	59.564	.000	59.564	1.000
Error(PowerLevel)	Sphericity Assumed	1502.633	12	125.219				
	Greenhouse-Geisser	1502.633	6.427	233.782				
	Huynh-Feldt	1502.633	6.694	224.478				
	Lower-bound	1502.633	6.000	250.439				
StrokeType * PowerLevel	Sphericity Assumed	67.952	2	33.976	.997	.398	1.994	.184
	Greenhouse-Geisser	67.952	1.375	49.416	.997	.377	1.371	.155
	Huynh-Feldt	67.952	1.649	41.212	.997	.387	1.644	.168
	Lower-bound	67.952	1.000	67.952	.997	.357	.997	.135
Error(StrokeType*PowerLevel)	Sphericity Assumed	409.025	12	34.085				
	Greenhouse-Geisser	409.025	8.251	49.575				
	Huynh-Feldt	409.025	9.893	41.344				
	Lower-bound	409.025	6.000	68.171				

a. Computed using alpha = .05

Table 47: Repeated measures ANOVA for male participants

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
StrokeType	Sphericity Assumed	.572	1	.572	.016	.905	.016	.051
	Greenhouse-Geisser	.572	1.000	.572	.016	.905	.016	.051
	Huynh-Feldt	.572	1.000	.572	.016	.905	.016	.051
	Lower-bound	.572	1.000	.572	.016	.905	.016	.051
Error(StrokeType)	Sphericity Assumed	220.160	6	36.693				
	Greenhouse-Geisser	220.160	6.000	36.693				
	Huynh-Feldt	220.160	6.000	36.693				
	Lower-bound	220.160	6.000	36.693				
PowerLevel	Sphericity Assumed	3066.146	2	1533.073	55.268	.000	110.537	1.000
	Greenhouse-Geisser	3066.146	1.270	2414.832	55.268	.000	70.175	1.000
	Huynh-Feldt	3066.146	1.456	2105.655	55.268	.000	80.479	1.000
	Lower-bound	3066.146	1.000	3066.146	55.268	.000	55.268	1.000
Error(PowerLevel)	Sphericity Assumed	332.864	12	27.739				
	Greenhouse-Geisser	332.864	7.618	43.693				
	Huynh-Feldt	332.864	8.737	38.099				
	Lower-bound	332.864	6.000	55.477				
StrokeType * PowerLevel	Sphericity Assumed	1.298	2	.649	.182	.836	.364	.072
	Greenhouse-Geisser	1.298	1.538	.844	.182	.782	.280	.069
	Huynh-Feldt	1.298	1.965	.661	.182	.832	.357	.072
	Lower-bound	1.298	1.000	1.298	.182	.685	.182	.065
Error(StrokeType*PowerLevel)	Sphericity Assumed	42.826	12	3.569				
	Greenhouse-Geisser	42.826	9.228	4.641				
	Huynh-Feldt	42.826	11.788	3.633				
	Lower-bound	42.826	6.000	7.138				

a. Computed using alpha = .05

Table 48: Repeated measures ANOVA for female participants

APPENDIX J -- Correlation Scatter Plots

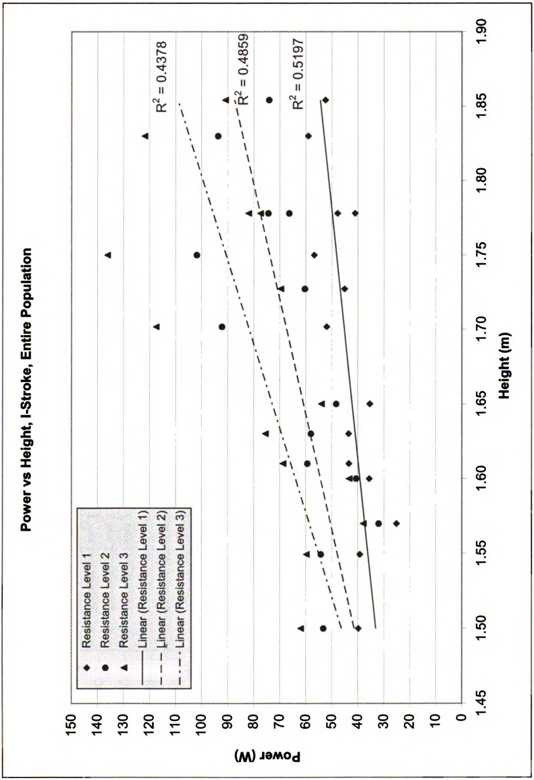

Figure 18: Power versus height for the I-Stroke, entire population

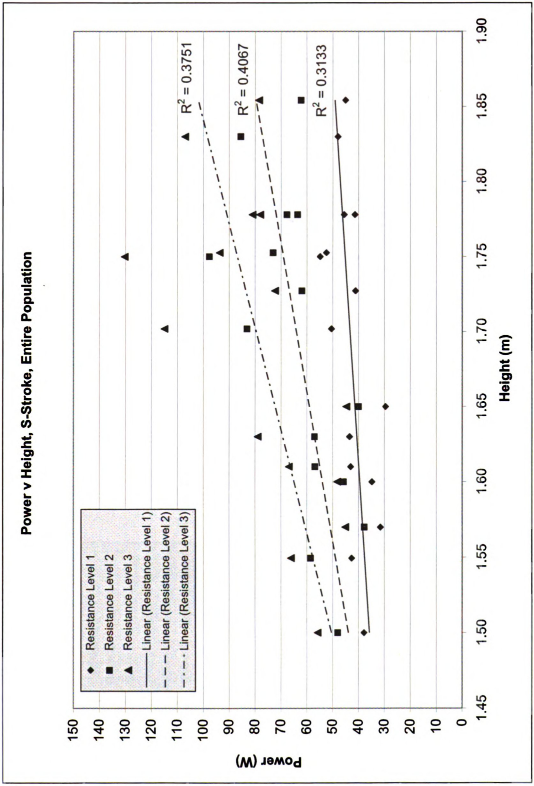

Figure 19: Power versus height for the S-Stroke, entire population

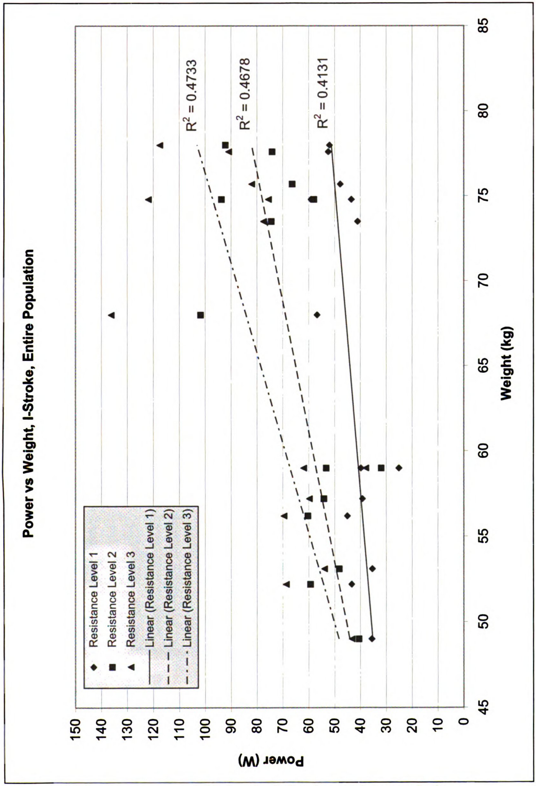

Figure 20: Power versus weight for the I-Stroke, entire population

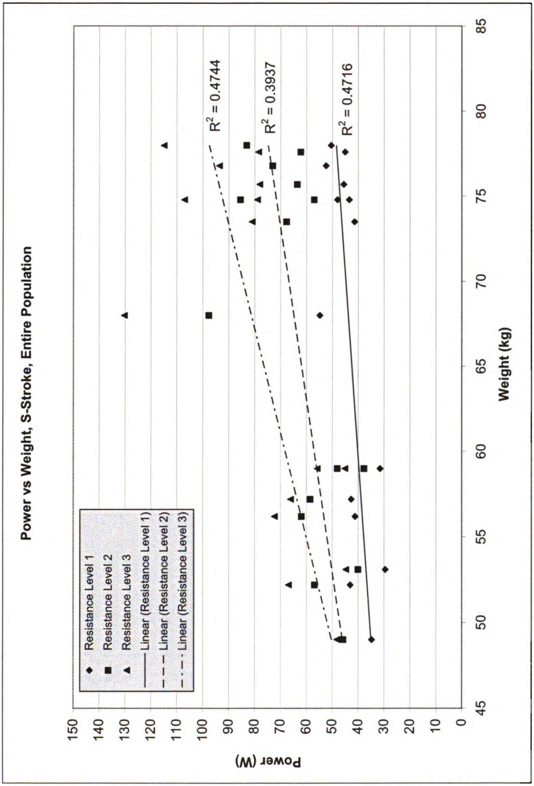

Figure 21: Power versus weight for the S-Stroke, entire population

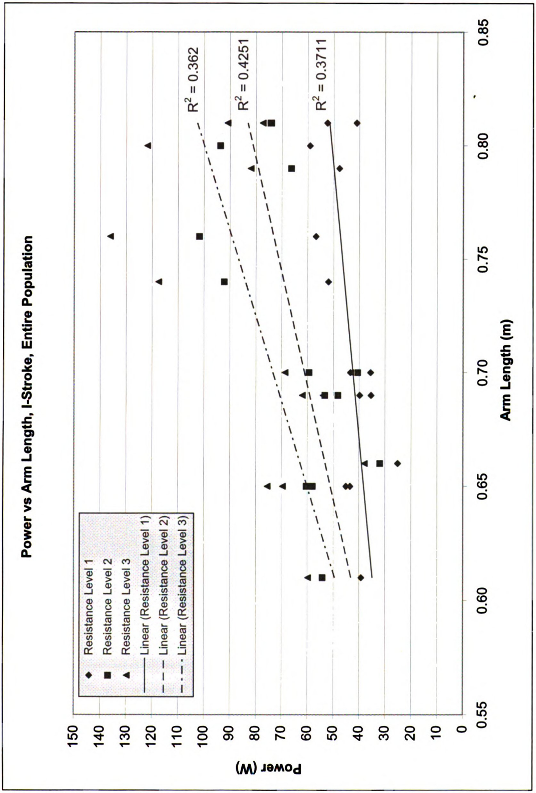

Figure 22: Power versus arm length for the I-Stroke, entire population

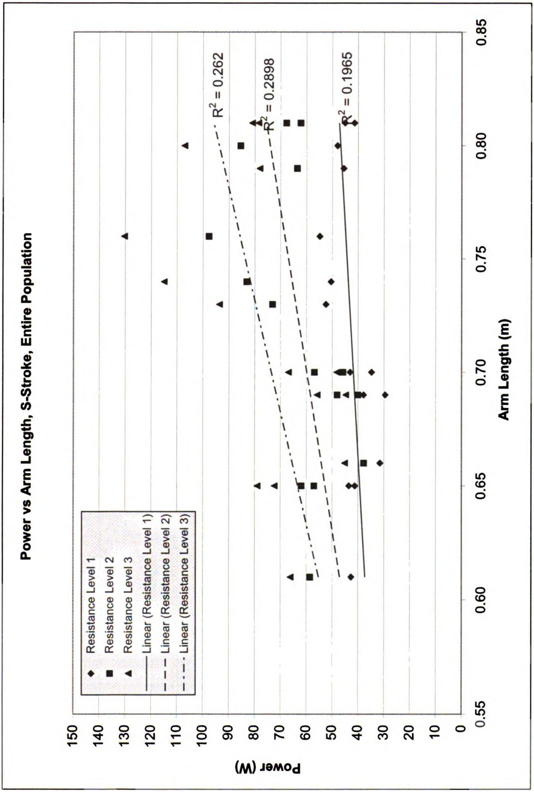

Figure 23: Power versus arm length for the S-Stroke, entire population

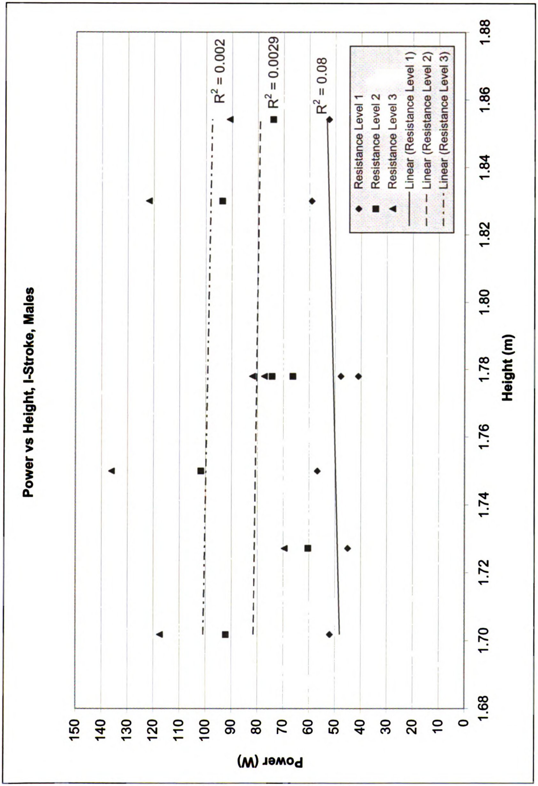

Figure 24: Power versus height for the I-Stroke, males

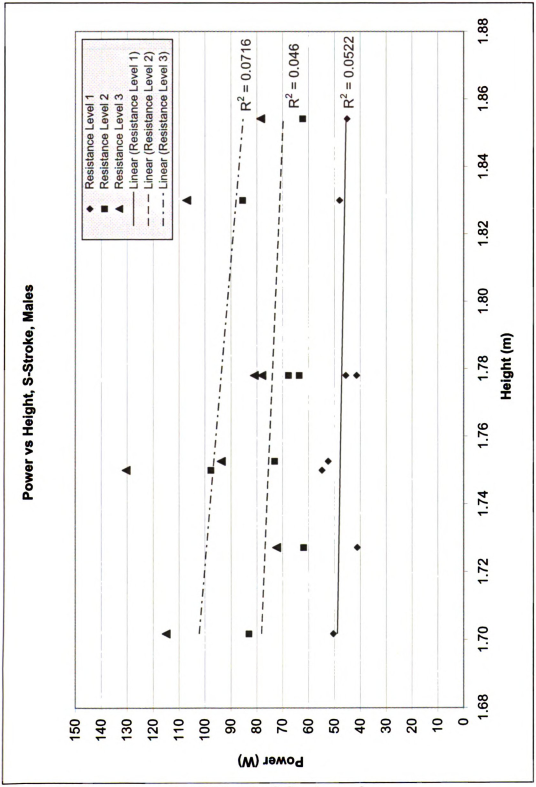

Figure 25: Power versus height for the S-Stroke, males

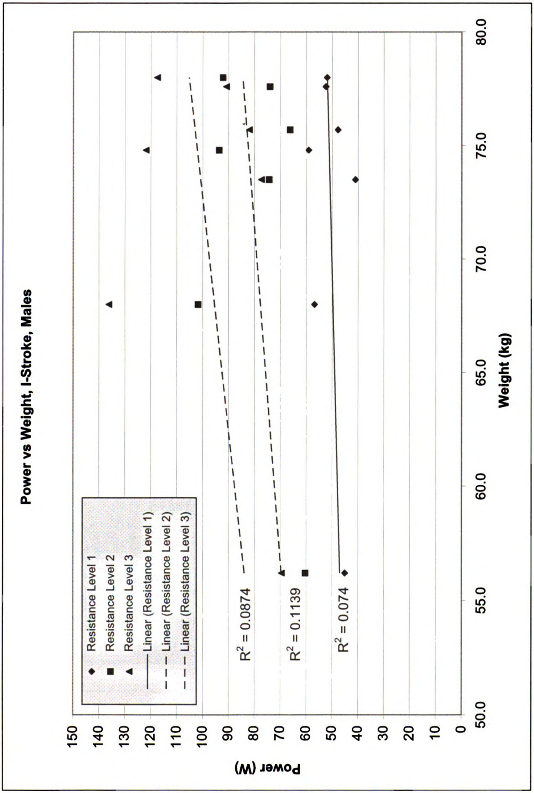

Figure 26: Power versus weight for the I-Stroke, males

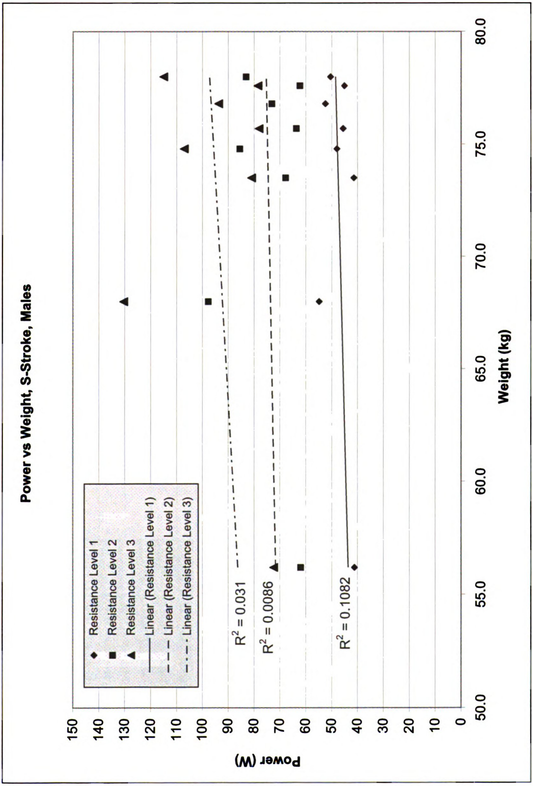

Figure 27: Power versus weight for the S-Stroke, males

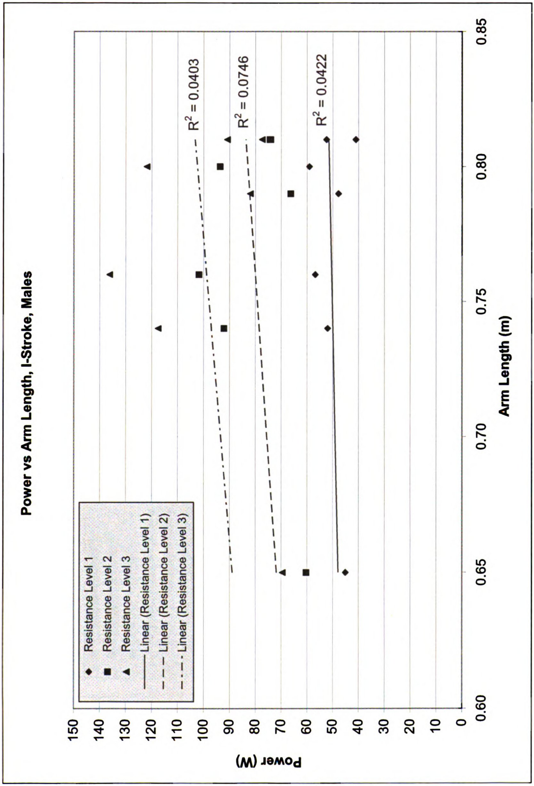

Figure 28: Power versus arm length for the I-Stroke, males

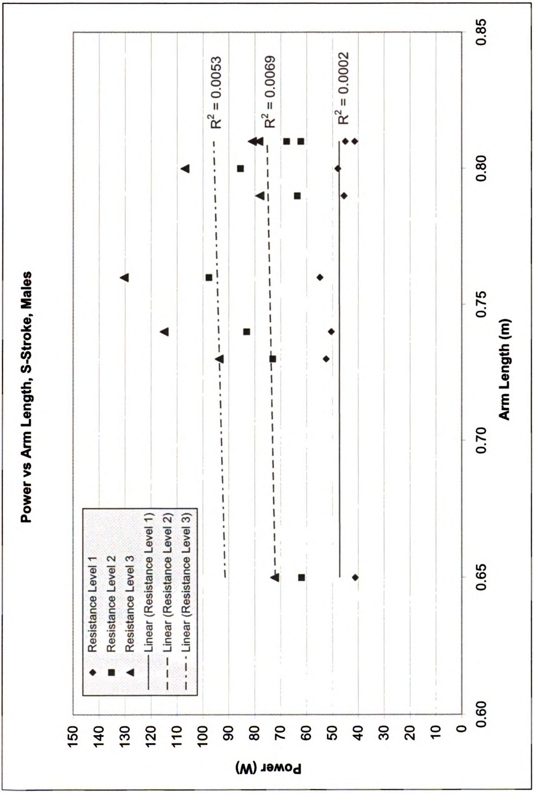

Figure 29: Power versus arm length for the S-Stroke, males

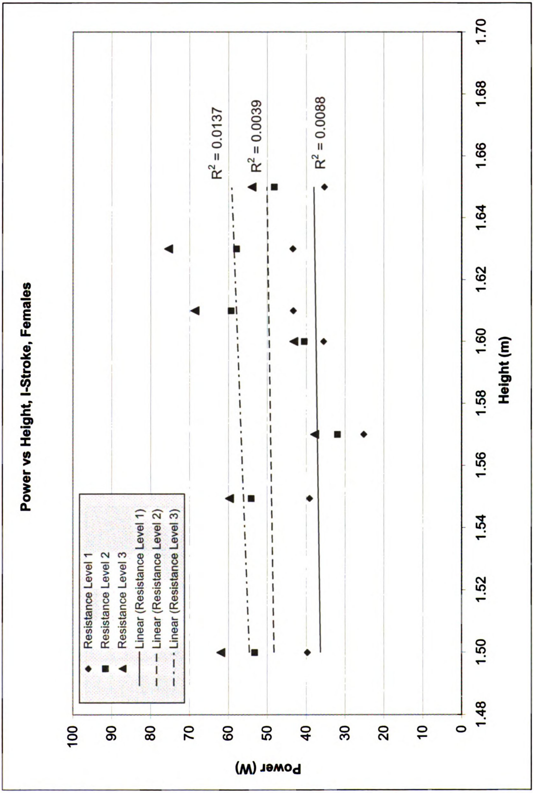

Figure 30: Power versus height for the I-Stroke, females

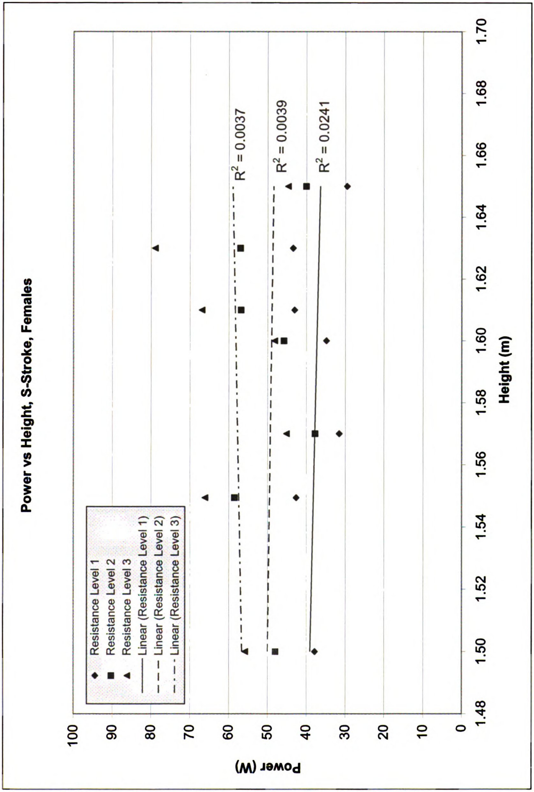

Figure 31: Power versus height for the S-Stroke, females

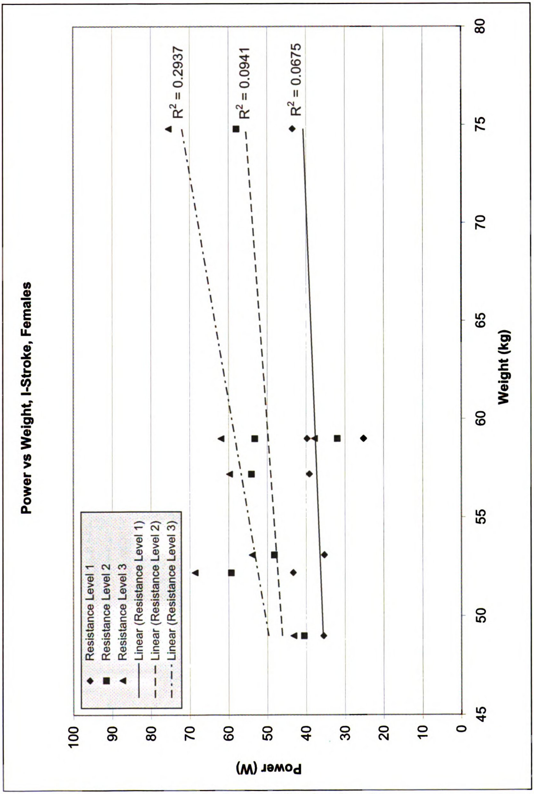

Figure 32: Power versus weight for the I-Stroke, females

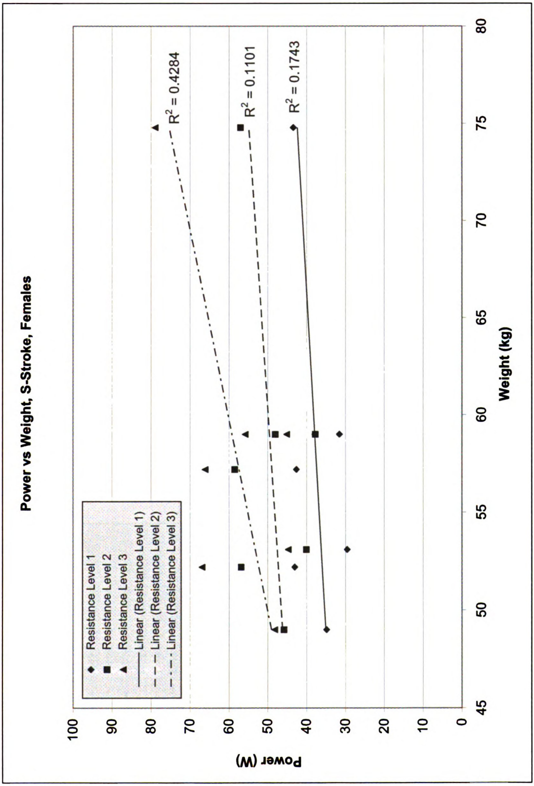

Figure 33: Power versus weight for the S-Stroke, females

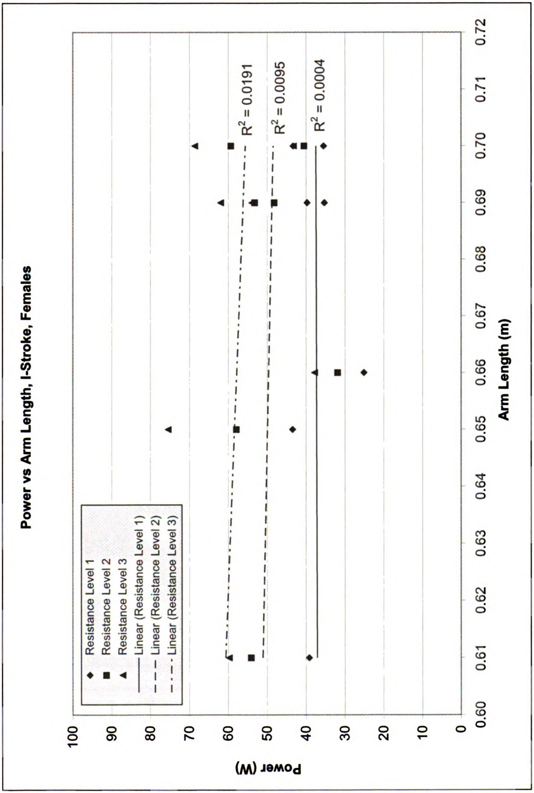

Figure 34: Power versus arm length for the I-Stroke, females

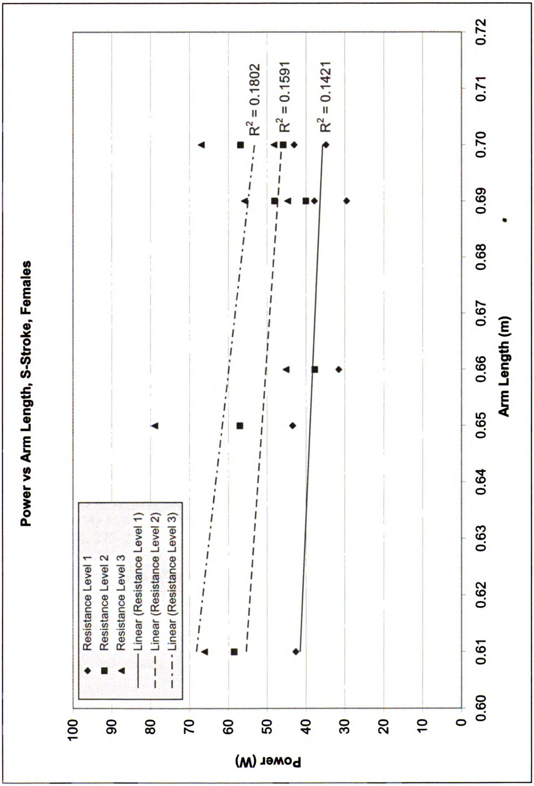

Figure 35: Power versus arm length for the S-Stroke, females

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