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A Kinematic analysis of novice freestyle swimmers

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Usher, Ronald Scott, M.A.

San Jose State University, 1993

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A KINEMATIC ANALYSIS OF
NOVICE FREESTYLE SWIMMERS

A Thesis

Presented to

the Faculty of the Department of Human Performance

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

Ronald Scott Usher

May, 1993

APPROVED FOR THE DEPARTMENT OF HUMAN PERFORMANCE

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APPROVED FOR THE UNIVERSITY

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ABSTRACT

A KINEMATIC ANALYSIS OF NOVICE FREESTYLE SWIMMERS

by Ron Usher

The purpose of this study was to conduct a kinematic analysis of novice freestyle swimmers. There were 12 subjects, 5 female and 7 male, between 11 and 14 years of age. The underwater propulsive phase of the right arm was investigated. The stroke patterns, linear displacements, velocities, accelerations, and angular kinematic data were described. A correlational analysis was performed comparing the velocity of the hip with various parameters.

This study revealed that novice swimmers display a wide variety of stroke and velocity patterns. The subjects in this study displayed: 1) elongated downsweeps and shortened insweeps when compared to highly skilled swimmers, 2) hip velocities that were greatest during the upsweep, 3) angular displacements of the wrist, hand, and forearm at the finish of the upsweep that differed greatly from those of highly skilled swimmers.

There were moderate to moderately high correlations between hip velocity and best 50 freestyle time, displacement of the hip, and angle of the hand at the start of the upsweep.

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CHAPTER 1

Introduction

Competitive swimmers are constantly seeking methods to improve performance. One way to accomplish this is to increase stroke efficiency. The more effective the underwater portion of the stroke, the faster the swimmer will swim (Barthels, 1982). Stroke mechanics are the most important aspects in developing swimmers (Troup, Plyley, Sharp, & Costill, 1982). According to these authors, stroke mechanics are the overriding factor which influence swimming speed and must be taught first, before strength or endurance training. Schleihau, a leading expert in swimming biomechanics, contends that the underwater portion of a swimmer's stroke is most important and the only aspect worth analyzing (Laughlin, 1988).

Some swimmers are slower than others because they are not as efficient (Miyashita, 1975; Piette & Clarys, 1978; Toussaint, van der Helm, Elzerman, Hollander, de Groot, van Ingen Schenau, 1982; Ungerechts, 1978). By improving stroke mechanics slower swimmers may become more efficient and thus swim faster (Schleihau, 1976; Toussaint et al., 1982; Ungerechts, 1978).

Unfortunately, very little research has been conducted on developing swimmers and what has been completed is primarily physiological in nature (Matheson, 1979). Most studies have analyzed collegiate and world-class athletes (Counsilman, 1971; Maglischo, Maglischo, Sharp, Zier, & Katz, 1984; Schleihau, Gray, & DeRose, 1982). Even at the elite level of swimming, efficient stroke mechanics becomes the critical

factor in being the best versus the near best (Craig, Boomer, & Gibbons, 1978; Toussaint et al., 1982).

Research has shown that elite swimmers make optimal use of the three key kinematic parameters in efficient swimming: hand pitch, hand velocity, and pull pattern (Schleihauf, 1974). Reischle (1974) believed that kinematic parameters determine swimming performance. For novice swimmers, there is an unfortunate shortage of kinematic information on the three key parameters. Therefore, there appears to be a great need for more analyses of the kinematic parameters of novice swimmers' performances.

This study quantified novice age-group swimmers performing the freestyle stroke and analyzed the underwater portion of the stroke. Hand displacement, velocity, and acceleration were calculated, and arm propulsive patterns were identified.

Purpose of Study

The purpose of this study was to describe a kinematic analysis of the freestyle stroke of novice age-group swimmers, ages 11-14 years. Hand displacement, velocity, acceleration, and individual stroke patterns for each individual were identified and compared.

Delimitations

The scope of the study was delimited to:

1. right-handed age-group swimmers;
2. 12 subjects who were between 11 and 14 years old;

3. subjects who had been swimming competitively for at least six months;
4. subjects who had not achieved Pacific Association A time standard in any freestyle event (50-100-200); and
5. subjects who volunteered for the study.

Limitations

The results of this study are subject to the following limitations:

1. subjects' racing stroke patterns may vary due to the effects of diet, fatigue, psychological, or motivational considerations;
2. possible variances in each stroke that the swimmer takes; and
3. digitizing errors due to obscured joint segments, either from body parts or refraction from sunlight.

Definition of Terms

Age-group swimmers. Age group swimmers are between the ages of eight and eighteen who swim on a competitive swim team.

Downsweep. The downsweep begins as the hand catches the water and continues until the hand begins the in sweep (Appendix A, Figure 1) (Maglischo, 1982).

Drag. Drag is the sum of all forces that act in a direction parallel to the direction of the fluid flow (Appendix A, Figure 2) (Hay, 1985).

Entry. The entry is defined as the moment when the hand enters the water after completing the recovery (Counsilman, 1968; Maglischo, 1982).

Freestyle. The overarm front crawl stroke as defined by United States Swimming (United States Swimming Rules and Regulations 1992, 1992).

Hand-pitch. Hand pitch is the angle of attack the hand makes during the pulling pattern (Appendix A, Figure 3) (Schleihauf, 1974).

Hand-velocity. Hand velocity is the speed and direction of the hand as it sweeps through the water (Maglischo, 1982; Maglischo et al., 1984; Schleihauf, 1974).

Insweep. The insweep is the portion of the pull that starts at the end of the downsweep and ends at the beginning of the outswEEP (Appendix A, Figure 1) (Maglischo et al., 1984).

Lift force. Lift force is the force that is perpendicular to the direction of flow (Appendix A, Figure 2) (Hay, 1985; Maglischo, 1982).

Novice swimmers. Novice swimmers are swimmers who have not achieved Pacific Association A time standards.

Pull. The pull is defined as the complete underwater portion of the arm cycle in swimming. In freestyle, the pull is composed of three main sweeps; downsweep, insweep, and upsweep (Appendix A, Figure 1) (Maglischo, 1982; Maglischo et al., 1984).

Recovery. The freestyle recovery starts at the completion of the pull and ends as the hand enters the water. It is the portion of the arm stroke that the arm is out of the water (Maglischo, 1982).

Resultant force. The resultant force is formed from the combination of lift and drag forces. It has a greater magnitude than either the lift or drag forces, and is directed somewhere between the lift and drag forces (Appendix A, Figure 2) (Maglischo, 1982).

Sweep. Sweep is a term used to describe a lateral direction the hand makes underwater. (Barthels & Adrian, 1975; Maglischo, 1982; Maglischo et al., 1984.)

Upsweep. The upsweep is the final portion of the underwater pull. It begins at the end of the insweep, and continues until the recovery (Appendix A, Figure 1) (Maglischo, 1982; Maglischo et al., 1984).

Velocity. For the purposes of this study, velocity is defined as the displacement in X of the hip divided by time for one stroke cycle.

CHAPTER 2

Review of Literature

An understanding of swimming kinematics in novice swimmers may be developed by reviewing the literature. This review will include: (a) an introduction to swimming propulsion theory, (b) cinematographic research, (c) distance per stroke (D/S), and stroke rate (S/T) investigations, and (d) qualitative descriptions of freestyle errors.

An Introduction to Swimming Propulsion Theory

Initially, swimming coaches felt that swimmers propelled themselves through the water by pushing back directly underwater (Schleihauf, 1974). Counsilman (1971) was the first to propose the use of lift forces and sculling movements for swimming propulsion.

Counsilman (1971) filmed world-class swimmers. By taking stroke tracings of their underwater stroke patterns, he noticed that the swimmers pulled in an S-shaped pattern or an inverted question mark. Counsilman also noticed that some swimmers' hands finished the pull in front of the entry position. He realized that pushing the water directly backward would not let the hand finish in front of the entering point. Counsilman (1971) proposed that efficient swimmers used their hands like airplane propellers. The hand sweeps through the water, creating both lift and drag forces which act perpendicular to each other. Water flowing over the dorsal side of the hand moved faster than water on the palmer surface thus creating lift forces. Drag forces

were created in the direction the hand traveled. The resultant of these two forces could be used to propel the swimmer forward (Appendix A, Figure 4).

Counsilman thought that efficient swimming results from the proper use of hand pitch and pull pattern to create forces which can be applied in the forward direction. It is the combined effect of lift and drag forces that causes swimmers to move forward. Elite swimmers make better use of these forces and create more lift and resultant forces than drag forces (Barthels & Adrian, 1975; Maglischo, Maglischo, Higgins, Hinricks, Luedtke, Schleihau, & Thayer, 1986; Schleihau, 1974).

In an effort to determine the magnitude of the lift and drag forces swimmers create, Wood (1978) made models of the hand and forearm in the shape of three national-caliber swimmers. He subjected these models to wind tunnel tests at various pitches and angles of hand orientation: distal, radial, and ulnar. Wood filmed one swimmer to determine the magnitude and nature of the forces generated throughout the stroke. He concluded that swimmers use subtle changes of combination of lift and drag forces.

In the first of a two part study, Schleihau (1978) made plastic models of the hand with various finger-thumb positions and subjected the models to an open-water channel. Lift and drag measurements were quantified with strain gauges at various sweep back angles and pitches. Schleihau's results with using models suggested that a swimmer can generate more lift by keeping the fingers together, and that a fully abducted thumb will create greater lift than a partially abducted thumb.

Additionally, Schleihau reported that the lift and drag coefficients can be used to determine both the lift and drag forces, and then the resultant force can be calculated. The resultant force values were compared with a swimmer tethered to a known load. The results supported Schleihau's methodology. Schleihau (1978) concluded that Counsilman (1971) was correct and that lift and drag forces interact to cause swimming propulsion.

Cinematographic Research

Film has been used to study swimmers for quite some time (Counsilman, 1968). In many studies, film has been used in conjunction with other instrumentation, such as EMG or tethered forces, to analyze swimmers. Some studies have used light-trace photography to study swimmers. This section of the review of literature will be limited to studies in which the primary purpose was to analyze the swimmers with film data.

Maglischo et al. (1986) examined six distance freestylers (three women and three men) from the U.S. Olympic Swim Team. Each subject swam 25 m at his/her Olympic qualifying pace. Stop watches were used to ensure that each swimmer was swimming at the correct pace. The tip of the middle finger, the base of the index finger and little finger, and the wrist were marked with black tape or battery operated lights. Two 16 mm LOCAM movie cameras with underwater housings were placed in the pool, one on the bottom of the pool to record underneath views, and the other placed perpendicular to the sagittal plane of the swimmer's motion.

Both cameras were synchronized at 66 frames per second. Every frame was digitized for a complete stroke of both the left and right arms. Maglischo et al. analyzed the film data using a computer software program written by Robert Schleihau. This program yielded the stroke patterns, hand velocities, and hand angles of attack from the side, bottom, and front views. The middle finger was used as the reference point to calculate hand velocity and all four markings were used to calculate the angle of attack. These data, along with the data from Schleihau's (1978) previous study, were used to determine the total force produced by the swimmers' arms.

The freestyle patterns were divided into four phases: downstroke, insweep, outstroke, and upstroke. Maglischo et al. found that each swimmer was able to generate maximal propulsive power in only one or two of the four phases, and that each swimmer tended to be either laterally or vertically dominated in his/her choice of strokes. The swimmers who were vertically dominated generated little or no force in the lateral directions (in and outstrokes). The lateral dominated swimmers had the same effect in the down and upstrokes. They also found that the swimmers were not able to maintain maximum power for more than .15 s and were only able to do this twice in each stroke cycle. There were several hypotheses given to explain the results, including that swimmers may only emphasize the portion of the stroke that is the most efficient for them. Another reason might be that the swimmers are not able to maintain pressure on the water after accelerating longer than .15 s.

Maglischo (1983a) filmed 10 of the best swimmers in the world and a less efficient swimmer (48 sec in the 100 yd freestyle) using two 16 mm cameras placed at 90 degrees to each other. The film speed was 49 frames per second. Hands, wrists, elbows, shoulders, hips, knees, ankles, and feet were digitized. The forward speed of the hips was used to determine forward velocity. All four strokes (backstroke, breaststroke, butterfly, and freestyle) were analyzed. For freestyle one complete stroke cycle was used. The results showed that all swimmers produce greater velocity with one hand than the other. The results also showed a large fluctuation in the velocity throughout a single arm pull.

Using the data from the previous study, Maglischo (1983b) analyzed the butterfly of Mary T. Meagher, a world-class swimmer. The velocity of the hands in three directions (forward/back, up/in, and down/out) was discussed. He found that Meagher performed her insweep relatively late in the stroke.

Schleihau (1985) conducted a kinematic analysis of 25 highly-skilled (sub 50 second) 100 yard freestylers. Three cameras were placed in a tri-axial set-up. The right and left side cameras were placed 4.3 m away from the center camera. The right side camera was 5.2 m and the left side 6.1 m ahead of the front camera. The trial with the most centered arm stroke was chosen for analysis. The middle finger tip, the index finger metacarpal phalangeal (MP) joint, the little finger MP joint, the wrist, and the waist were all marked with lights. The elbow joint, shoulder joint, and clavicular notch were marked, but not lighted.

Schleihauf concluded that stroke pattern angles greater than 80 degrees or less than 40 degrees were considered as signs of a stroke defect. Schleihauf found that the beginning of the stroke was not as effective for generating forward velocity and suggested that it not be emphasized. Each of the elite swimmers analyzed used the last portion of the stroke to generate the most force with the hand pitched at approximately 30 degrees. The most variance of the stroke was found in the middle portion of the stroke.

Barthels and Adrian (1975) investigated intercollegiate butterflyers by filming their stroke patterns. They used two 16 mm cameras, synchronized with an underwater light bulb. The film speed was approximately 44 frames per second. A timing light unit on the side of the camera was used to determine precise speeds. Film analysis reference points included the distal end of the third finger of the right hand (used to represent the hand), and a point on the right hip (used to represent the body). The points from the film and computer programs were used to determine displacement and velocity values for the right hand for forward, backward, upward, downward, and lateral motion.

Barthels and Adrian's data showed common patterns for each of the swimmers with each swimmer having individual variations. The authors suggested that lift and drag forces were responsible for forward propulsion in swimming. They also found that the underwater portion of the pull can best be described as a three-dimensional pattern.

In the second part of his two part study, Schleihau (1978) filmed swimmers performing all four strokes. Schleihau used two cameras, one underneath the swimmer and one at the side. The film speed was 45 frames per second. The subjects wore four miniature light bulbs on the hand so that the lift, drag, and resultant forces could be derived with data from the first part of his study. The variables used to derive the forces were hand velocity, sweepback angle, plane of motion, and angle of pitch. With these data, Schleihau was able to tell how much force a swimmer generated at any given portion of his/her stroke. While filming freestyle swimmers, three different general patterns were identified. The first is the classic technique and was characteristic of skillful hand pitch manipulation. According to Schleihau, Bruce Furnise and Mark Spitz used this style. The next technique was used by Carolyn Schwanhauser who does not use as much sculling motion. This is compensated for by an increased stroke rate. The third type of pattern was used by Jim Montgomery. The finish was similar to the classic style, however, in the middle portion of the stroke he pushed directly backward.

Wiegand, Werensch, and Jaehnig (1985) filmed male and female swimmers of various abilities while swimming at different velocities. One 16 mm camera was placed underwater and recorded the swimmers as they swam by. The wrist and hip were used to determine displacements. Wiegand and associates divided the strokes into four phases: introductory, propulsive, transitional, and preparatory. They found that these phases were independent of the swimmer's velocity or ability and proposed

that by quantifying the strokes into phases, coaches have an effective way of evaluating an athlete's development.

Reischle (1974) filmed 60 highly skilled age-group swimmers and 44 untrained physical education students using light-streak photography. Reischle was trying to find kinematic parameters that determine performance and develop quantitative data that supported optimal stroke patterns for swimmers. He compared their strokes and found that the trained swimmers had less angle of hand entry, less backwards displacement of the hand, and that the hand left the water closer to, or in front of, the point of entry.

Hoecke and Gruendler (1975) also used light-trace photography to study swimmers. Endoscope lamps with a waterproof battery were placed at the ankle, hip, and the top of the middle finger. The optical axis was at right angles to the path of the swimmer when the swimmer was approximately 7 meters away. The swimmers swam about 40 meters at constant speed and the middle section of the swim was within the optical field of the lens.

Hoecke and Gruendler show swimmers in various stages of learning butterfly and freestyle. They found that beginning swimmers already display consistent pulling patterns. For one beginning freestyle swimmer, the arm pull was not divided into stages, the kicking motion came most from bending at the knee, and his body displayed excessive rotation around the longitudinal axis. As the swimmer's skill progressed, the film data revealed improved technique. A similar study was done for

a swimmer performing butterfly. Hoecke and Gruendler (1975) concluded that pictures of performances at different stages of learning can be used for developing movement concepts, correction of errors, and methodological instruction.

Persyn, Hoeven, and Daly (1978), and Persyn, Daly, Veruaecke, Van Tiborgh, and Verhetrsel (1982), used kinematic analysis to help design a stroke evaluation center for swimmers. These researchers were concerned with obtaining cinematographic, motor anthropometric, physiological, and medical data and combining the results so that a complete profile would be available to the coach for each swimmer. Persyn and associates were interested in general movement patterns and were not concerned with detailed quantitative information. Persyn et al. (1978) compared the strokes of top swimmers with 7 skilled 12-14 year-olds. Persyn and associates filmed from the front and side and examined body velocity fluctuations and balance problems (variations from the right and left hands). One swimmer was analyzed for stroke problems and they were corrected.

Distance Per Stroke and Stroke Rate Studies

Some studies have looked at stroke rate and the distance covered per stroke. This can be measured with film, video tape, or by counting the number of strokes and noting the time it takes for a swimmer to cover a certain distance. These studies are important because they show the value of having an efficient pull.

Using film, and taking physiological readings, Toussaint et al. (1982) looked at seven female Olympic swimmers and seven lower level competitive swimmers. Their

respective average times for the 100 meter freestyle were 57.3 and 103.9 seconds. The subjects anthropometric data were taken, as was a maximum VO₂ test. The swimmers were filmed so that the stroke frequency and distance per stroke could be measured. The authors found no significant differences in the ability to generate power, VO₂ max, or stroke frequency between the two groups. There was significant difference in stroke length. They concluded that elite swimmers are more efficient and coaches should work on improving stroke technique.

Craig et al. (1979) measured S/T and D/S with a tethering device that gave virtually no resistance. An observer recorded the number of strokes and the time it took to swim them. The swimmers performed repeated swims from very slow speeds to maximum speed. The authors found that up to a certain point D/S and S/T increase as velocity increases. At maximum velocity, there is a unique combination of D/S and S/T. If a faster S/T is attempted the velocity decreases. The authors have used this technique to measure the ability of their swimmers and to aid in stroke analysis. By increasing the stroke efficiency and decreasing body drag the swimmers are able to improve their D/S.

Qualitative Descriptions of Freestyle Errors

Counsilman's book The Science of Swimming (1968) includes descriptions of stroke errors. He stresses the importance of horizontal and lateral body alignment to reduce drag. According to Counsilman, poor horizontal position may be caused by: (1) lifting the head to breathe; (2) making the catch directly downward; and or (3)

finishing the pull with a straight elbow. Poor lateral alignment may be caused by: (1) recovering the arm in a wide circular motion; (2) pulling the arm too far underneath the body; (3) lateral flexion of the head, especially during breathing; (4) slowing the hand down as it starts its entry; and (5) extending the shoulder during the stretch.

Counsleman stressed the importance of keeping the elbow up during the pull, and of flexing the elbow to approximately 100 degrees. The hand should pull in a “S” pattern or an inverted question mark. He pointed out that there are three types of pulls; the S pull, the inverted question mark pull, and the modified straight line pull.

Colwin (1977) states that there are three types of freestyles due to the timing of the release and catch of the opposite arm. Like Counsilman (1968), he stressed the importance of keeping a high elbow position and of bending the elbow to approximately 90 degrees. He found common swimming errors to be: (1) reaching across the center line during the stretch; (2) pulling too far past the center line; (3) initiating the pull too quickly; and (4) leading with the elbow as the hand pulls.

The ESSO Swim Canada Instructors' Manual (1982) recommends that for success in freestyle, swimmers should try to be smooth in the transition from one pull to another. Swimmers should have good body alignment as they roll from one side to the other. They also should have equal movements from the left and right hands.

In order to keep a high elbow the swimmers should start the pull with the hand first and then the forearm. The upper arm starts pulling when the forearm is vertical.

During the middle portion of the stroke the swimmer's elbow should point out. The manual recommends that the hand not be cupped but should be flat.

Maglischo (1982) described using sweeping motions and proper angles of attack. He does an excellent job of using graphs to show how common errors slow down forward speed. For each section of the stroke he sites common errors. For some errors there are pictures of what a swimmer would look like making this error.

Summary

The review of literature was presented in five areas: (a) an introduction to swimming propulsion, (b) cinematographic research, (c) distance per stroke and stroke rate investigations, and (d) qualitative descriptions of freestyle errors.

It appeared that swimmers, at least the majority of the good ones, employ a combination of lift and drag forces to swim (Barthels & Adrian, 1975; Schleihau, 1978). Cinematographic research has centered on collegiate and world class athletes and their kinematic parameters have been described (Schleihau, 1978; Maglischo et al., 1985).

Studies (Maglischo, Maglischo, Zier, & Santos 1985; Maglischo et al., 1984) found by using tethering and film that tethering may be detrimental to stroke mechanics. Toussaint et al. (1982), and Craig et al. (1978), found that stroke rate and distance per stroke vary according to swimming velocity, and that better swimmers have greater distance per stroke, rather than increased stroke rate or greater physiological parameters.

There have been numerous qualitative studies of swimming errors (Colwin, 1977; Counsilman, 1968; ESSO Swim Canada Instructors' Manual, 1982; Maglischo, 1982); however, little quantitative research has been done on novice swimmers.

CHAPTER 3

Methodology

Subjects

Participants in this study were four 11-12 year-old females, three 11-12 year-old males, one 13-14 year-old female, and four 13-14 year-old males. All subjects had been members of a United States Swimming (USS) swim team for at least six months. Age, weight, and height were measured (Appendix B) and personal best competitive times in the 50, 100, and 200 yds freestyle events were recorded (Appendix C). All subjects were B swimmers who have not achieved a Pacific Association A time standard (1992 Pacific Swim Guide) for the 50, 100, or 200 yard freestyle events. These time standards are presented in Table 3 (Appendix D). All subjects were volunteers whose parents had signed a human subjects consent form (Appendix E). Release forms, along with letters of introduction (Appendix F) and statement of protocol (Appendix G) were handed out at swim practice on Monday, March 23, 1992.

Pilot Study

A pilot study was conducted one week prior to the videotaping for the study, using one subject who was not in the study. This preliminary study determined the best location for the videocameras, the camera to subject distance, and time of day to videotape.

Videotography

Each subject was videotaped performing three trials of a freestyle sprint. There was a minimum of 5 minutes between trials. Each subject started to sprint 20 seconds after the previous subject had completed his/her sprint. A half-inch diameter yellow rope was placed at the start of the sprint and stretched on the surface of the water to the finish of the sprint to be used as a guide by the subjects to ensure they would enter both cameras' field of view. Subjects were instructed not to breathe the last half of the sprint. The trial that was most centered on videotape from both cameras was used for digitization.

A Panasonic AG450 Super HS video camera and a Panasonic D5000 video camera were used in the videotaping. The videotape was TDK High Standard color. A calibration frame was videotaped and digitized to establish real distance from image size. The videotaping was done near the end of the 15 yd swim due to the configuration of the pool (Appendix A, Figure 5). The weather was warm (80 degrees fahrenheit) and the conditions were bright and sunny with the sun behind the videocameras. Videotaping began at 4:00 pm and was finished at 5:15 pm.

Videographic Data Collection

A Peak Performance 3-D Motion Analysis System provided by the San Jose State University Biomechanics Laboratory was used for the videotaping. The video recording portion of this system consists of two video cassette recorders (VCR), a Panasonic AG6300 VCR, and a Panasonic AG2400 VCR. The two VHS shuttered

video cameras were a Panasonic D5000 with Genlock facility, and a Panasonic AG450S. The cameras were synchronized at picture rate 60 fields per second.

The Peak system calibration frame was used to establish real size and distance. The calibration frame was placed upside down and the upper four legs were inserted into the water (Appendix A, Figure 6). A pole was used to place and hold the frame in the water. Eight non-linear reference points on the calibration frame were in both cameras' field of view. These points defined the X, Y, and Z axes. The X axis was placed in the subjects' direction of travel.

The data were collected using the Peak Performance 3-D Motion Analysis system. The collection portion of this system consists of Peak Video/Computer Motion Measurement Software, an Everex 286 computer (AT compatible), and an EGA Graphics card.

Videocamera #1 was 3 meters underwater, approximately 6 meters, and 45 degrees counterclockwise from the X axis of the calibration frame. Videocamera #2 was 3 meters underwater, approximately 8 meters from the subjects, and 15 degrees clockwise from the X axis of the calibration frame (Appendix A, Figure 7).

The following reference points were used having been adapted from Maglischo et al. (1984): (1) tip of the middle finger of the right hand; (2) joint center of the wrist of the right hand; (3) center of the elbow of the right arm; (4) center of the shoulder of the right arm; and (5) insertion point of the right leg at the hip.

Data Reduction

The stroke parameters analyzed were: (1) stroke patterns in the sagittal, transverse, and the frontal planes; (2) total time for the propulsive phase of the stroke; (3) time, angular displacement, and angular velocity of the hand in each sweep (adapted from Maglischo et al., 1984); (4) maximum acceleration of the hand during the propulsive phase; (5) linear velocity of the hip; and (6) the angle the hand and forearm made with the transverse plane.

Protocol

The videotaping took place on Wednesday, April 1, 1992 at 4:00 pm at the Foothill College pool in Los Altos, California (Appendix A, Figure 5) and was finished at 5:15 pm. The subjects did a 20 minute warm-up of approximately 800 yards. The subjects were instructed to swim freestyle at top speed next to a guide rope. The subjects were also instructed not to breathe the last half of the sprint. Subjects sprinted to the end of the pool where they got out and walked back to the starting point. After one subject left the water another subject would start 20 seconds later. This allowed sufficient time for the turbulence in the water to subside.

Analysis of Data

All trials were observed on the video monitor. The trial in which the subject was most centered in both cameras' field of view was used for the digitizing. The digitizing was started two frames forward from the point where the fingers entered the water. The digitizing program was in the point prediction mode.

The data were reduced using an Epson 386SX computer and Microsoft Excel software. The subjects' descriptive and kinematic data were correlated with their computed velocity (DPS in X at the hip/Time for stroke). Correlation data were computed using a rank difference correlation coefficient

$$\rho = 1 - (6 - (\sum D^2) / N (N^2 - 1))$$

where D is the difference between the two ranks of each subject, D^2 is the square of the difference, and $\sum D^2$ is the sum of D^2 for all subjects (Safrit, 1986).

The downsweep, insweep, and upsweep were determined by observing the strokes on the Peak graphics' program. When it appeared that the motion of the finger had changed from being one of primarily downward to inward that is where the insweep started. When the motion went from primarily inward to upward that was the start of the upsweep. Frequently there was no definitive point where the change in sweeps was made. This was especially true during the transition from downsweep to insweep. The hand might still be traveling downward as it moved inward.

The data were analyzed for measures of central tendency and variability. A rank order correlation (Safrit, 1986) was done using the subjects ranked in order of greatest velocity. Greatest velocity was the distance traveled by the hip in the X direction divided by the time of the underwater stroke.

Summary

This chapter contained the methods and techniques used in this study to analyze the kinematics of novice freestylers. The subjects were 12 swimmers 11-14

years of age who had been swimming for at least six months. All subjects had not recorded a Pacific Association A time standard for their age group in a freestyle event. A Peak Performance 3-D Motion Analysis System using two videocameras recorded the propulsive portion of the subjects performing a freestyle sprint. This system allows a movement which takes place in three dimensions to be quantified. The displacement, velocity, and acceleration of the hand were studied, along with the angles of the wrist, elbow, and shoulder. In addition the angle of the hand and forearm with the transverse plane was examined. Parameters were compared to a rank order correlation with the subject's velocity.

CHAPTER 4

Results

The purpose of this study was to use 3-D analysis to describe the movement of novice swimmers performing the freestyle. Two video cameras placed under water recorded twelve 11 to 14 year olds performing the freestyle. Stroke patterns for each subject were identified and described. Hand displacement, velocity, and acceleration were calculated along with the angular displacement and velocity of each subject's wrist, elbow, and shoulder. The angle the hand and forearm made with the transverse plane were calculated. A correlational analysis was performed comparing selected parameters with the velocity of the hip in the X (sagittal axis) direction.

The results are displayed in six sections: (1) the results of the pilot study are discussed; (2) the subjects' descriptive data is given; (3) the stroke patterns are shown in graphic form; (4) the linear kinematics are shown in tables and graphs; (5) displays of the angular kinematic data; and (6) the correlation data.

Pilot Study

The results from the pilot study showed that the underwater windows and the rooms they were located in were adequate for videotaping the subjects. The placement of the video cameras and their height were also determined. The best location of the calibration frame was determined for maximum viewing in both video cameras' viewing field. It was also found that the best time to videotape was later in the afternoon due to less refracted light from the sun.

Subjects

The 12 subjects were between the ages of 11 and 14 years old. There were 5 female subjects and 7 male. The mean age was 12.58 years. The mean weight, height, arm length, and hand width were 49.64 kilograms, 1.59 meters, .67 meters, and .08 meters respectively. The subjects' descriptive data are summarized in Table 1 (Appendix B). The subjects' best time in the 50, 100, and 200 yd freestyle events are given in Table 2 (Appendix C).

Stroke Patterns

The stroke patterns of each swimmer's right hand are displayed in Figures 8-18 (Appendix A). The patterns were obtained by taking the linear coordinates of the tip of the middle finger of the right hand for each subject and plotting the coordinates using the Excel graphics' program. The sagittal plane or side views were graphed using the X/Y coordinates taken from the Peak system printout. These points were referenced from the subject's right side. The transverse plane or posterior view was located as if the subject were swimming away from the reader. These points were graphed using the Z/Y coordinates. The frontal plane or top view was graphed using the Z/X coordinates. The location of the axis and the stroke plots were determined by the location of the subject on the monitor when the digitizing was performed.

When looking at the stroke patterns the points give the illusion of three-dimensional movement. The points show the stroke pattern and the speed of the

middle finger. The closer the points are together the slower the movement and the farther apart the points, the faster the movement.

Figure 20 (Appendix A) shows the sagittal view of each subjects' position at the start of the upsweep. These views are a printout of the Peak Performance graphic display.

Linear Kinematics

The downsweep, insweep, and upsweep were determined by observing each subjects' stroke on the Peak graphics program on the video monitor. The insweep was judged to have started when it appeared that the motion of the finger had changed from being one of primarily downward to that of inward. The upsweep was judged to have started when the motion went from primarily inward to upward. The finish of the upsweep was the last field of view. As the subject's middle finger travelled from the downsweep to the insweep, it frequently continued downward. Similarly, in the transition from the insweep to the upsweep the finger continued moving inward while it was moving upward. This made determining the point of transition ambiguous causing the transition points to be estimated.

The linear displacement data for the finger, elbow, shoulder, and hip are displayed in Tables 4-7 (Appendix H). The displacements were derived by subtracting the value of the coordinate at the beginning of a sweep from its value at the end of the sweep.

During the downsweep the mean of the greatest movement of the middle finger tip was .70 meters in the X or superior direction. During the insweep the greatest mean displacement of the middle finger was in the X direction, -.35 meters. During the upsweep the mean displacement was almost equal in the X, Y, and Z directions—.38 meters, .32 meters, and .27 meters respectively.

The displacement of the elbow is shown on Table 5 (Appendix H). The mean displacement of the elbow was similar to the middle fingers for both the downsweep and insweep. During the upsweep the elbow moved less than the finger in the X (forward) and Z (lateral) directions (-.068 and .065 meters respectively).

The mean displacement of the shoulder was .796 meters in the X direction during the downsweep. During the upsweep the shoulder traveled only .277 meters.

The hip traveled the greatest distance in the X direction for all three sweeps with the most forward movement during the downsweep. Mean movement in the X direction for the hip during the downsweep was .786 meters, insweep .331 meters, and upsweep .428 meters. The greatest movement of the hip in either the Y or Z directions was during the downsweep. The mean value of the hip was -.129 meters in the Y direction and -.108 in the Z direction.

Tables 8-11 (Appendix I) show the linear velocities of the middle finger, elbow, shoulder and hip at the start and finish of each sweep. The values were determined by taking the velocity at the start of the downsweep, insweep, and

upsweep and the finish of the upsweep. These values do not reflect changes in velocity that may have taken place during the sweeps.

The middle finger had the highest two mean resultant velocities at both the start of the downsweep and the finish of the upsweep, 3.25 and 3.59 meters per second, respectively. The elbow had its greatest velocity at the start of the downsweep, corresponding with the finger, but then had much smaller velocities throughout the rest of the pull. The mean velocities of the hip and shoulder were similar in all sweeps and directions.

The maximum, minimum, mean, and resultant velocities of the finger are shown in Table 12 (Appendix J). These values were produced from the Peak Performance System and are for the entire underwater portion of the stroke. The maximum value for all subjects occurred during the upsweep with a mean value of 4.57 meters per second.

The maximum, minimum, and mean velocities of the hip in the sagittal plane (X direction) are shown in Table 13 (Appendix J). All subjects showed a large variance in the velocity of the hip. The negative value for the minimum of subject A.G. was the initial value of the downsweep and is probably a result of a digitizing error.

Figures 22-33 (Appendix K) show the change in velocity over time for the X, Y, Z, and resultant (R) velocities of the middle finger. The slopes of the graphs indicate the change in velocity. A rising slope shows an increase in velocity, while a

decreasing slope shows a decrease in velocity. The steeper the slope the faster the change in velocity. The sign of the velocity determines the direction. A + sign means the direction of velocity is forward or superior.

The graphs of X, Y, and Z show the highest velocities are in the X direction at the start of the pull. The X velocity decreases throughout the pull and then increases at the end. Some subjects showed a bimodal increase, but most subjects showed one peak at the end of the pull. For all subjects the Y velocity remained relatively constant through the first half of the pull and then showed rapid increases at the finish of the pull. The Z velocity tended to start off greater than the Y velocity, taper off, and then accelerate at the end of the pull.

The resultant velocities showed the wide variety of pulling velocities that the subjects used during the propulsive phase. Most tended to start high, decreased during the middle, and again showed increases in velocity at the end of the pull. However, some of the graphs show one, two, or three peaks in resultant velocity throughout the pull.

Figures 34-45 (Appendix L) display the velocity of the hip in the X direction. The graphs show the wide variety of velocity patterns used by the subjects. Most have peaks at the end of their strokes with the middle portions displaying one or more peaks. Some of the peaks are sharp with quick drop offs, others maintain the increased velocity over longer periods of time.

Table 14 (Appendix M) shows the maximum, minimum and mean accelerations of the finger. These data were taken directly from the Peak printout. The mean minimum value was 4.87 meters per second per second. The mean maximum value was 56.04 meters per second per second.

The percentage of time that each subject took each sweep and the total time propelling underwater are shown in Table 15 (Appendix N). The downsweep took up almost 50% of the time during the propulsive phase of the stroke. The mean percentage of time in the insweeps and upsweeps was 22.3% and 23.6%, respectively.

Angular Kinematics

The angular displacements of the wrist, elbow, and shoulder at the start of each sweep are shown in Table 16 (Appendix O). Also shown is the angle of the hand and forearm with the transverse plane. The mean value of the angle of the wrist was 167.2 degrees. For the elbow bend during the insweep the mean value was 141.6 degrees. The mean angle of the shoulder was 154.7 degrees. The hand and forearm entered the water at mean angles of 57.7 and 64.6 degrees with respect to the transverse plane.

The angular displacements at the start of the insweep are shown in Table 17 (Appendix O). This table does not indicate the changes that may have taken place during the downsweep. The mean angular displacement of the wrist was 162.3 degrees, the elbow 147 degrees, and the shoulder 131.7 degrees. The hand and

forearm decreased their mean angles about 10 degrees to 46.8 and 52.37 degrees, respectively.

At the start of the upsweep (Appendix O, Table 18) the mean angles of the wrist showed little change. The mean value for the bend of the elbow was at 93.4 degrees. The smallest angle was 54.6 degrees, the largest 124.5 degrees. The mean value of the shoulder angle was 55.8 degrees. The hand and forearm moved closer to being parallel with the transverse plane. Their mean angles were 23.6 and 26.7 degrees, respectively.

Table 19 (Appendix O) shows the angles of displacement at the finish of the upsweep. At the finish of the stroke the mean angle of the wrist was 154.5 degrees. The mean angle of the shoulder at the end of the pull was 107.2 degrees. There was a substantial amount of variance in this parameter with a standard deviation of 27.9 degrees. The mean angle at the shoulder was 18.4 degrees. The mean angles of the hand and forearm with the transverse plane were 27.5 and 28.7 degrees, respectively.

Correlational Data

The correlations were performed in an effort to find a relationship between swimming velocity and kinematic parameters. All kinematic and descriptive data were compared to the subjects' velocity (hip displacement in X/time in stroke).

Comparisons were also done with maximal and minimal velocities and accelerations.

The correlations were computed using the rank difference correlation coefficient. The interpretation of the coefficients is as follows (Safrit, 1986):

$\pm .80-1.00$	High
$\pm .60-.79$	Moderately high
$\pm .40-.59$	Moderate
$\pm .20-.39$	Low
$\pm .00-.19$	No relationship

The descriptive correlations are presented in Table 20 (Appendix P). The correlations of velocity with weight, height, and arm length were low. There was a moderate correlation with age (.45) and a moderately high correlation of .63 with best time in the 50 yard sprint.

Table 21 (Appendix P) presents the linear displacement correlations with velocity of the finger, elbow, shoulder, and hip. The correlations were between none and very low for most of the parameters examined. The highest elbow displacement correlation was with the resultant displacement during the upsweep (-.53). The shoulders' highest correlation was -.70 with resultant displacement during the upsweep. The hips' displacement correlations were moderate during the insweep with a value of -.53 in the X (anterior/posterior) direction and a moderately high value of -.63 in the Z (lateral) direction.

Table 22 (Appendix P) shows the linear velocity correlations and displacement correlations. The middle finger had moderate correlations at the start of the insweep

($Z = -.47$ and $R = .48$), the start of the upsweep ($X = .53$, $Y = .57$, and $R = .48$), and the finish of the upsweep ($X = .46$).

The resultant velocity of the elbow during the insweep had a moderate correlation of .46. The shoulder had moderate values at the start of the downsweep ($Y = .45$ and $R = .41$), the start of the insweep ($Y = .56$), and the start of the upsweep ($X = -.55$ and $R = -.49$).

The hip had a negative correlation of $-.58$ in the Z direction during the downsweep. During the upsweep there were moderately high correlations of .62 in the X and .64 in the resultant directions.

Table 22 (Appendix P) displays the correlations of the velocity of the hip in the X direction with the angular displacements at the start of the downsweep, insweep, upsweep, and the finish of the upsweep. There were moderate correlations of $-.48$ for the forearm during the beginning of the downsweep. During the start of the upsweep there were correlations of $-.45$ for the wrist and $-.39$ for the hand. At the start of the upsweep the hand had a moderately high correlation of .62. During the finish of the upsweep the hand had a correlation of $-.43$ and the forearm of .50.

Summary

This chapter presented the results of a 3-D kinematic analysis of novice freestyle swimmers. The subjects were 12 swimmers between the ages of 11 to 14 years. Each subject's stroke pattern was presented from the sagittal, posterior, and frontal views. Hand displacement, velocity, and acceleration were described in tables

and graphs along with the angular displacements and velocities of the wrist, elbow, and shoulder joints, and the angle the hand and forearm made with the transverse axis. A correlational analysis was performed comparing subjects' velocities to the parameters described.

CHAPTER 5

Summary, Conclusions, and Recommendations

The purpose of this study was to videotape 12 novice freestyle swimmers, ages 11 to 14 years and describe the stroke patterns of their right arms. Using the Peak 3-D Motion Analysis System, a three dimensional analysis was performed and the following parameters were studied:

1. Stroke patterns in the sagittal, frontal, and transverse planes were identified and described. Graphs of the velocity of the middle finger and the hip on the longitudinal axis were given.
2. Hand displacement and velocity were calculated for the downstroke, insweep, and upstroke of the finger, elbow, shoulder, and hip. The acceleration of the middle finger was described. The means and standard deviations of all subjects for each of these parameters were calculated.
3. The displacement and velocity of the wrist, elbow, and shoulder angles were recorded as well as the angle of the hand and forearm with the transverse plane. The means and standard deviations of all subjects for each of these parameters were calculated.
4. A correlational analysis was performed comparing these parameters with each subject's swimming velocity. Swimming velocity was determined by the displacement of the hip in X/time in pulling.

Summary

The kinematic parameters of the freestyle stroke by novice swimmers were studied. Twelve right handed subjects who had been swimming for a minimum time of six months and had not achieved a Pacific Association A time standards were selected. There were 5 female and 7 male subjects between 11 and 14 years of age. Subjects performed a 15 m sprint and one right arm pulling cycle was videotaped by two underwater cameras.

The pulling patterns in the sagittal, frontal, and transverse planes were shown for each of the subjects. The velocities of the middle finger on the longitudinal axis (X), anteroposterior axis (Y), and the transverse axis (Z), and the resultant vector (R) were graphed, along with the velocity of the hip in the X direction. Subjects showed a wide range of propulsive and velocity patterns. There was a strong tendency for the resultant velocity to increase near the end of the pull. The positions of the limbs at the final frame of digitizing for each subject were shown.

The displacements and velocities of the middle finger, elbow, shoulder, and hip of the right arm during the downstroke, insweep, and upsweep were given. The middle finger had the greatest displacement during the downstroke. The hip had the greatest displacement during the downstroke. The velocity of the middle finger was highest at the entry point and during the upsweep for each subject.

The graphs of the resultant velocity of each subject's middle finger revealed that the subjects used a wide variety of pulling velocities. Most subjects started with

high resultant velocities, decreased velocity during the middle of the pull, and finished with high velocities. Subjects did display one, two, or three peaks during the pull.

The graphs of each subject's velocity of the hip in the X direction were shown. There was a wide variety of patterns. Most subjects had peak velocities at the end of the pull but the middle portion displayed one or more peaks.

Subjects' arms spent approximately 50% of their time underwater during the downstroke. The times for the inswings and upswings were approximately equal.

The angular displacements and velocities of the wrist, elbow, and shoulder joints were given for each of the swings. The angle the hand and forearm made with the transverse plane was also recorded.

A rank difference correlation was computed comparing stroke parameters with the hip's velocity in the X direction. There were moderately high correlations with the subjects' best 50 yd freestyle time, resultant displacement of the shoulder during the upstroke, the hip's displacement in the Z direction during the inswing, and during the upstroke in the X and resultant directions. The angle of the hand at the start of the upstroke also had a moderately high correlation. Most parameters had no or low correlations with the subjects' swimming velocities.

Stroke patterns.

The sagittal stroke patterns of the subjects were similar but tended to be more elongated during the downstroke than the ones that have been cited as being by the elite swimmers, such as Mike Heath and Mark Spitz (Maglischo, 1984; Schleihau et

al., 1984). Spitz and Heath both have a moderately sloped entry but they have a pronounced point where their fingers move downward at a steeper angle. Maglischo (1984) calls this point the catch. The subjects in this study do not show this catch.

The subjects in this study displayed an insweep that tended to take place at a later portion of the stroke and did not have as much upward travel. They also covered less distance laterally than the elite swimmers. The closeness of the points indicated the slower speed that the swimmers exhibit through this section of the stroke.

The upsweeps appeared to be less vertical than the elite swimmers. Unfortunately, as explained previously, frequently it was not possible to digitize the entire upsweep. Of the subjects that were digitized until their hands left the water, all hands finished forward of the entry point. It can be observed that the subjects finished the upsweep with an acceleration of their hands.

The frontal views showed that many subjects demonstrated large inward movement during the downsweep. This is opposite of the outward downsweeps that Spitz and Heath have (Maglischo, 1984; Schleihau et al., 1984). The sweeps of Olympic distance freestylers also showed greater outsweeps than the subjects in this study demonstrated (Maglischo et al., 1984). The frontal view also confirmed the small horizontal insweeps that take place later in the strokes and farther underneath their bodies. Some of the subjects showed a small horizontal movement outwardly during the upsweep.

The top views showed the trend towards inward movement during the downsweep and small lateral movement during the upsweep. They also displayed the upsweep finishing at or near the entry point. This indicated that the swimmers in this study might use lift in the propulsive phase of their strokes (Counsilman, 1971).

Linear Displacement.

Tables 4-7 (Appendix H) give the distances moved for each body part. As one would expect, since the middle finger is the most distal it showed the greatest displacement. It is interesting to note how little the elbow moved in the Y and Z directions. The elbow moved mostly forward in the X direction and down slightly as the arm extended during the downsweep, followed by very little movement throughout the rest of the propulsive phase. The studies that were researched had no data on the movement of the elbow.

Tables 6 and 7 (Appendix H) show how the hip and shoulder roll together as the swimmer propels him/herself. Again most of the movement took place in the X direction. This was surprising as the swimmers' main movement was forward.

The data on Tables 6 and 7 show little movement in the X or Y directions. On the videotapes it appeared the swimmers were getting quite a bit of body roll. This discrepancy might be because the digitizing was done from the joint centers, not the outside of the hip or shoulder. The subjects had the greatest roll during the downsweep and had the least roll during the insweep and upsweep.

Velocity of Hand and Hip Graphs.

It should be remembered that a negative velocity signifies deceleration and that the slope of the line shows how fast it was changing speed. Many of the subjects showed a relatively constant velocity (little slope) in at least one of the directions of travel. While there is not much literature to compare velocities, Schliehauf (1978) did analyze the velocities of Mark Spitz. The graphs showed very little constant velocity as compared to the subjects in this study. Schliehauf states that a positive hand speed early in the stroke is a sign of slippage. This would explain the lengthened stroke patterns seen in the sagittal views.

The subjects frequently had a velocity in the X direction that was greater than the Y and Z velocities. This indicates that the subjects were trying to get pressure backwards rather than laterally or vertically (Maglischo, 1983). The resultant velocity showed that most subjects had a large increase in velocity at the finish of their strokes. This occurs due to a combination of increasing velocities in at least two of the three directions. Some swimmers did have their greatest velocities during the insweep.

When comparing the velocities with better swimmers an obvious difference is the sharp peaks that Mark Spitz (Schliehauf et al., 1985) was able to generate versus the rounded peaks from the subjects in this study. This would indicate that better swimmers are able to change direction and accelerate their hands faster than novice swimmers. Even though the peak velocities for some swimmers approximate the faster swimmers, it takes the novice swimmers longer to generate that velocity.

In a study examining the propulsive phase of Olympic distance freestylers, Maglischo et al. (1985) presented graphs of the propulsive forces performed by five athletes. These graphs appear similar to the graphs of the resultant velocities of the subjects in this study. More research needs to be done to see if the forces novice swimmers produce are directly related to the resultant velocities of their hands.

Figures 34-45 (Appendix L) show the velocity of the hip throughout the pull. Adapting data from Maglischo (1983) the hip velocity graphs of better swimmers can be compared (Appendix L, Figure 46). Subjects in this study have lower average velocities and show more fluctuations in velocity. While the swimmers in Maglischo's study were not going at race pace, many of the subjects of this study were able to obtain hip velocities as great as the better swimmers, however, they were not able to maintain them for as long and dropped down to much slower velocities.

Linear Velocity.

Tables 8-11 (Appendix I) show the linear velocities at the beginning of each of the sweeps and at the finish of the upsweep. The negative values indicated that the subject was slowing down or decelerating at this point. It was interesting to look at the velocity of the elbow during the upsweep. There was a large degree of variance between the subjects' elbow velocities during the finish of the upsweep. Some of the swimmers might be lifting up with their elbows, and others might just have been extending their arms. There is no literature to compare with better swimmers.

Angular Kinematics.

The angle of the wrist at the start of the downsweep or entry was almost 180 degrees (mean angle 167.2 degrees). A smaller angle might mean that more of the forearm is facing the water as the arm slides in. The closer the angle is to 180 degrees the less resistance would be encountered.

The angle of the elbow at the entry varied from a maximum of 166 degrees to a minimum of 114 degrees. A larger angle might be advantageous due to having to extend less during the downsweep and thus creating less drag resistance. Similarly with the shoulder angle, a straighter angle would mean the forearm and upper arm would encounter less resistance because of less distance travelled.

The hand and forearm angles give an indication of the pitch they are making during the entry. One subject (J.H.) had an entry angle of 1 degree, which greatly increased the standard deviation. This subject, an 11 year old male, entered with his palm pushing the water forward which would create large amounts of drag force. Angles of attack are recommended to be around 60 degrees (Schleihauf et al., 1984). The mean of the subjects showed a close approximation to 60 degrees for both the hand and forearm angle.

At the start of the insweep the wrist angles of the subjects had changed very little. This showed that the forearm and wrist were rotating as a unit. The hands and forearms had moved closer to parallel with the transverse plane. It might be that the

recommended high elbow position at this point would yield smaller angles for the hand and forearm.

At the start of the upsweep, the wrist and forearm are working as a unit. The elbow had flexed to approximately 90 degrees. The hand and forearm were making less of an angle with the transverse plane, becoming closer to parallel.

Figure 20 (Appendix A) shows the position of each subject's limbs at the finish of the upsweep. The reader may observe how some subjects were not able to be digitized at the same portion of each stroke. Four of the subjects finished with their hands in extension. The remainder finished in flexion.

The difference in finishing angles between subjects in this study is obvious when compared to the finish of highly skilled swimmers. Mike Heath's finish (Appendix A, Figure 21) is typical of better swimmers (Schliehauf et al., 1985). The upsweep seems to be the most propulsive portion of the stroke for most swimmers, yet the subjects in this study show a large variance from those of better swimmers.

Correlational Data.

By examining the correlation of different parameters with the velocity of the hip new relationships might be explored. The linear displacement correlations showed some interesting tendencies. The elbow moving during the upsweep had a correlation of -.53. This could mean that it is more efficient to finish the upsweep by extending the hand rather than lifting the elbow. This is contrary to what some literature has recommended (Costill, Maglischo, & Richardson, 1992).

The other relatively high correlations were with the hip during the insweep. Perhaps the negative correlation of the hip in the X direction during the insweep is because it is better to have the greatest velocity of the hand during the upsweep. The -.63 in the Z was explained by the poor lateral alignment some of the swimmers showed.

The linear velocity correlations of the finger tip with velocity showed the importance of high velocity of the hand at the finish of the stroke. The angular displacement correlations showed the importance of hand pitch at the finish of the stroke.

Qualitative Comparison.

Councilman (1968), Colwin (1977), and the Esso Swim Canada Instructors' Manual (1982) stressed the importance of correct body alignment. The data from this study showed how much hip movement novice swimmers exhibit.

Councilman (1968) and Colwin (1977) also believe that swimmers should bend their elbows approximately 90 degrees. The subjects' elbows in this study approached 90 degrees during the insweep. The authors also point out that subjects should avoid pulling the arm too far underneath the body. In this study subjects M.T., C.L., and J.P. had pulls that crossed beyond the center line. This was observed by watching the videotape. The data were not able to substantiate this observation.

Councilman (1968) recommends against slowing the hand down during the entry. The subjects in this study had high velocities during the entry. He also

believed swimmers should not catch the water directly downward. The novice swimmers researched in this study had lengthened downsweeps suggesting that they do not have this stroke defect.

Councilman (1968) and Colwin (1977) also believe that the elbow should be kept high and not dropped. The videotape showed that some subjects did drop their elbows. Unfortunately, the data were not able to verify the dropped elbows.

Conclusions

This study showed that there was a tendency for subjects to have elongated downsweeps and insweeps that were short with little upward movement. Most subjects had high hand velocities at the beginning of the downstroke, and at the end of the upstroke. There was a wide variety of pulling patterns and velocities. The resultant velocity of the finger showed one, two, and three peak patterns.

The subjects' hips tended to have the greatest forward movement during the upstroke. The hips also had different velocity graphs for each subject. There was a tendency to have the greatest velocity during the upstroke but some swimmers had the largest velocities during the insweep. On video tape swimmers had a tendency to have poor lateral alignment.

The angles of the wrist, hand, and forearm during the finish of upstroke were different from those of more highly skilled swimmers. The most obvious difference between novice and elite swimmers was the extension of the wrist the elite swimmers

demonstrated. Correlational data supported the importance of hand angles at the finish of the upsweep.

Recommendations

This study showed that novice swimmers can be quantified using 3-D analysis. The researcher makes the following recommendations:

1. Use more videocameras which might allow all points to be seen and not be hidden from view.
2. Perform a full stroke analysis both above and below the water. This would allow both arms to be compared and the ability to explore the timing of the entry and release of the opposing arm.
3. Use a computer program to collect kinetic data on novice swimmers. This would provide better understanding of the propulsive phase of novice swimmers.
4. Establish a standard set of data to be collected. This would help researchers have a standard to compare swimmers of different abilities.
5. Use more subjects so that the correlational data can take on greater power.
6. Conduct developmental studies to determine if swimmers improve due to stroke improvements or other factors.
7. Conduct studies to determine if faster age group swimmers have stroke patterns that are similar to the world class swimmers or the novice swimmers.

8. Examine the stroke patterns of swimmers performing at different speeds.
9. Conduct a study to examine the effect of different stroke instructions on stroke mechanics.
10. Determine the effect of fatigue on stroke mechanics.
11. Determine the change in stroke mechanics over the course of a swimming season.

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APPENDIX A

Stroke Patterns

Figures 1 - 20

Figure 1. DownswEEP, Insweep, and Upsweep.

Figure 2. Drag, Lift, and Resultant Forces.

Figure 3. Hand Pitch.

Figure 4. Swimmer shown with forces.

Figure 5. Layout of Foothill College Pool.

Figure 6. Calibration Frame.

Figure 7. Close-up of underwater videotapping room and target area.

Figure 8. Subject A. G.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 9. Subject A. K.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 10. Subject C. C.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 11. Subject C. L.'s stroke patterns in the Sagittal, Frontal, and Top Views.

H. K. Frontal View

H.K. Top View

Figure 12. Subject H. K.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 13. Subject J. G.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 14. Subject J. H.'s stroke patterns in the Sagittal, Frontal, and Top Views.

J. P. Sagittal View

J. P. Frontal View

J. P. Top View

Figure 15. Subject J. P.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 16. Subject L. H.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 17. Subject L. S.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 18. Subject M. T.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 19. Subject S. R.'s stroke patterns in the Sagittal, Frontal, and Top Views.

Figure 20. Limb positions of study subjects at the start of the upsweep.

A = tip of middle finger, B = wrist, C = elbow, D = shoulder, E = hip.

Figure 21. Mike Heath's limb position at the start of his upsweep.

A = tip of middle finger, B = wrist, C = elbow, D = shoulder, E = hip.

APPENDIX B
Subjects' Descriptive Data

Table 1

Subjects' Descriptive Data

Subject	Sex	Age	Weight (Kg)	Height (M)	Arm length (M)	Hand width (M)
A.G.	F	12	45.33	1.53	0.65	0.08
A.K.	M	14	51.22	1.68	0.74	0.07
C.C.	M	13	53.94	1.69	0.67	0.09
C.L.	M	12	60.74	1.60	0.71	0.09
J.G.	M	14	57.57	1.77	0.74	0.09
J.H.	M	11	40.34	1.47	0.60	0.08
J.P.	M	13	45.78	1.49	0.60	0.08
L.H.	F	14	41.70	1.58	0.66	0.08
L.S.	M	11	43.97	1.54	0.65	0.08
H.K.	F	14	61.20	1.67	0.72	0.08
M.T.	F	12	55.30	1.67	0.74	0.08
S.R.	F	11	38.53	1.41	0.60	0.07
Mean		12.58	49.64	1.59	0.67	0.08
S.D.		1.24	8.04	0.11	0.06	0.01

APPENDIX C

Subjects' Best Times for Freestyle Events

Table 2

Subjects' best time for freestyle events (Seconds)

Subject	50 yards	100 yards	200 yards
A.G.	31.20	1:08.78	2:31.54
A.K.	29.31	1:04.87	2:16.45
C.C.	29.94	1:03.91	2:14.14
C.L.	32.05	1:10.66	2:34.78
J.G.	32.11	1:14.85	2:45.23
J.H.	32.60	1:17.96	2:47.15
J.P.	29.36	1:03.50	2:12.74
L.H.	33.56	1:19.32	2:51.80
L.S.	33.14	1:14.89	2:52.08
H.K.	29.79	1:06.27	2:21.49
M.T.	32.53	1:13.65	2:48.77
S.R.	33.24	1:12.96	2:33.14

APPENDIX D

1992 Pacific Association Freestyle A Time Standards

Table 3

1992 Pacific Association freestyle A time standards (Seconds)

Boys		50	100	200
11 & 12	Yards	30.59	1:07.49	2:25.89
	Meters	34.69	32.59	31.09
13 & 14	Yards	27.59	59.49	2:09.99
	Meters	31.39	1:07.49	2:26.99
Girls				
11 & 12	Yards	30.79	1:07.19	2:25.59
	Meters	34.89	1:15.99	2:44.19
13 & 14	Yards	29.49	1:03.79	2:18.49
	Meters	33.49	1:12.19	2:36.39

APPENDIX E

Consent Form

RESPONSIBLE INVESTIGATOR: Ron Usher

TITLE OF PROTOCOL: A Kinematic Analysis of Novice Freestylers.

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Your child is invited to participate in a research study that is investigating the freestyle stroke in novice swimmers. The results of this study should further our understanding of swimming propulsion.

I understand that:

1. my child will be asked to swim approximately 20 yards at top speed, two to four times. Each trial will take ten to fifteen seconds, with at least five minutes of rest between trials. My child will be video taped by a video camera that is behind an underwater window. This study will be performed at the Foothill College swimming pool, Los Altos Hills, Ca.
2. the probability and magnitude of harm or discomfort are minimal, and are no greater than encountered during a typical swim practice. This discomfort may include muscle fatigue and soreness, along with increased heart and breathing rates.
3. the possible benefits of this study to my child are to use the data and results so that he or she may swim more efficiently or faster.
4. the results of this study may be published, but any information from this study that can be identified with my child will remain confidential and will be disclosed only with my permission.
5. the video tapes will be kept at the San Jose State University Biomechanics Laboratory and erased at the completion of the study.
6. any questions about my child's participation in this study will be answered by Ron Usher, (408) 287-7723. Complaints about the procedures may be presented to Gail Evans, Graduate Advisor, Department of Human Performance. For questions or complaints about research subject's rights, or in the event of research-related injury, contact Serena Stanford, Ph.D. (Associate Academic Vice President for Graduate Studies & Research) at (408) 924-2480.
7. my consent is given voluntarily without being coerced; my child may refuse to participate in this study or in any part of this study, and I may withdraw my consent at any time, without prejudice to my relations or my child's with SJSU, or with Los Altos Mountain View Aquatics Club.
8. I have received a copy of this consent form for my file.

HAVING READ THE INFORMATION PROVIDED ABOVE, I HAVE MADE A DECISION WHETHER OR NOT MY CHILD MAY PARTICIPATE. MY SIGNATURE INDICATES THAT MY CHILD MAY PARTICIPATE AND IS WILLING TO PARTICIPATE.

DATE__ PARENT'S/GUARDIAN'S SIGNATURE_____

PRINT CHILD'S NAME_____

RELATION TO CHILD:_____

INVESTIGATOR'S SIGNATURE_____

APPENDIX F

Letter of Introduction

Dear Parent:

I need your help in conducting a study on the swimming strokes of children. The results of this study should increase our understanding of how children propel themselves through the water. Attached is a consent form that describes the procedure that is involved. Please spend a few minutes to read the form and mail it or hand deliver it to me before March 31st.

You should be clear that your participation in this study is voluntary. Also, any information that could be used to identify your child will remain anonymous and could only be disclosed as required by law.

If you have any questions about this study, I would be happy to talk with you. I can be reached at (408) 287-7723. Your help will be greatly appreciated.

Sincerely,

Ron Usher
Graduate Student

APPENDIX G

Protocol

Protocol:

The purpose of this study is to investigate swimmers, eleven to fourteen years old. I am interested in video taping their strokes and describing the underwater portion. The original work was done using film by Doctor Counsilman in 1969. That and much of the recent work has been with college or world-class athletes. I feel there is a large gap of knowledge about young swimmers and how they propel themselves through the water.

I wish to investigate using kinematic measurements (displacement, velocity, acceleration) of the right arm pattern of age group swimmers performing freestyle.

Each subject will swim three to five sprints, of approximately twenty yards. Each sprint will last ten to fifteen seconds, with at least five minutes rest between repeats. Data will be collected using video cameras located behind underwater windows. The swimming pool to be used is at Foothill College, Los Altos Hills, Ca.

There will be three boys and three girls from two age groups, eleven to twelve and thirteen to fourteen for a total of twelve subjects. These subjects will be members of the Los Altos Mountain View Aquatics Club. The risks involved are minimal. The subjects will have been on a swim team for at least one year and are used to rigorous training. The sprints involved are just a fraction of what they do in a daily practice. The subjects may benefit by providing data that could help them improve their swimming efficiency.

APPENDIX H

Linear Displacements

Tables 4 - 7

Table 4

Linear Displacement of Finger (Meters)

Subject	Down Sweep				In Sweep				Up Sweep			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	0.96	-0.52	0.15	-1.02	-0.09	-0.05	-0.11	-0.02	-0.74	0.60	0.40	1.00
A.K.	0.59	-0.73	0.18	-0.82	-0.21	0.08	-0.16	0.19	-0.47	0.43	0.14	0.64
C.C.	0.12	-0.79	0.19	-0.57	-0.43	0.14	-0.12	0.36	-0.10	0.26	0.05	0.24
C.L.	0.84	-0.58	-0.03	-1.00	-0.41	-0.06	-0.18	0.38	-0.54	0.43	0.48	0.60
H.K.	0.94	-0.44	0.32	-0.37	-0.33	-0.14	-0.03	-0.30	-0.58	0.44	0.14	0.54
J.G.	0.51	-0.31	0.36	-0.25	-0.37	-0.26	-0.08	-0.30	-0.29	0.16	0.08	0.28
J.H.	0.80	-0.31	0.23	-0.02	-0.36	-0.11	-0.12	-0.14	-0.29	0.21	0.20	-0.28
J.P.	0.82	-0.60	-0.12	-0.16	-0.30	0.01	-0.21	-0.13	-0.32	0.18	0.37	-0.13
L.H.	0.76	-0.50	0.13	-0.70	-0.58	0.00	-0.29	0.19	-0.12	0.28	0.32	0.34
L.S.	0.97	-0.63	0.15	-0.56	-0.41	0.05	-0.17	-0.16	-0.33	0.25	0.28	0.40
M.T.	0.45	-0.65	-0.05	-0.75	-0.42	0.20	-0.11	0.42	-0.35	0.23	0.64	0.40
S.R.	0.70	-0.42	0.42	-0.80	-0.26	-0.22	-0.16	0.12	-0.47	0.37	0.15	0.58
Mean	0.70	-0.54	0.16	-0.58	-0.35	-0.03	-0.15	0.05	-0.38	0.32	0.27	0.38
S.D.	0.25	0.15	0.16	0.32	0.12	0.14	0.07	0.26	0.19	0.13	0.18	0.34

Table 5

Linear Displacement of Elbow (Meters)

Subject	Down Sweep				In Sweep				Up Sweep			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	1.056	-0.324	-0.056	-1.065	0.025	-0.063	-0.056	-0.023	-0.098	0.338	-0.179	0.202
A.K.	0.580	-0.422	0.133	-0.702	-0.143	0.113	-0.014	0.178	-0.019	0.260	-0.060	0.211
C.C.	0.633	-0.938	0.040	-0.693	-0.503	0.210	0.109	0.523	-0.095	0.185	-0.101	0.146
C.L.	0.769	-0.553	-0.105	-0.935	-0.083	-0.022	0.031	0.060	-0.060	0.422	0.084	0.270
H.K.	0.985	-0.441	0.007	-0.810	-0.118	0.060	0.118	0.086	-0.003	0.174	-0.197	0.160
J.G.	0.549	-0.316	0.049	-0.494	-0.255	0.076	0.063	0.159	0.077	0.091	0.851	0.042
J.H.	0.801	-0.314	0.232	-0.019	-0.360	-0.110	-0.120	-0.140	-0.290	0.208	0.201	-0.280
J.P.	0.962	-0.500	-0.159	-0.543	-0.101	-0.051	0.003	-0.087	0.027	0.237	0.062	0.229
L.H.	0.843	-0.428	0.048	-0.793	-0.182	-0.069	-0.023	0.018	0.142	0.346	-0.068	0.222
L.S.	0.969	-0.631	0.151	-0.555	-0.410	0.045	-0.017	-0.160	-0.330	0.249	0.277	0.400
M.T.	0.606	-0.600	-0.064	-0.851	-0.189	0.103	0.058	0.206	0.036	0.412	0.020	0.313
S.R.	0.741	-0.276	0.114	-0.777	0.014	-0.023	0.034	-0.021	-0.198	0.232	-0.109	0.282
Mean	0.791	-0.479	0.033	-0.686	-0.192	0.022	0.025	0.067	-0.068	0.263	0.065	0.183
S.D.	0.175	0.186	0.115	0.268	0.164	0.094	0.065	0.187	0.144	0.099	0.287	0.171

Table 6

Linear Displacement of Shoulder (Meters)

Subject	Down Sweep				In Sweep				Up Sweep			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	1.123	-0.185	-0.092	-1.081	0.190	-0.003	-0.003	-0.159	0.483	0.037	-0.097	-0.374
A.K.	0.797	-0.152	-0.039	-0.678	0.117	0.085	0.006	0.007	0.285	-0.039	-0.096	-0.142
C.C.	-0.699	-0.398	0.040	-0.693	-0.503	0.210	0.109	0.523	-0.095	0.185	-0.101	-0.146
C.L.	0.631	-0.307	0.045	-0.702	0.267	0.049	-0.025	-0.198	0.334	0.091	0.017	-0.205
H.K.	0.957	-0.229	-0.132	-0.687	0.245	0.039	-0.001	0.011	0.189	0.011	-0.028	0.038
J.G.	0.681	-0.267	0.155	-0.622	0.326	0.134	-0.193	0.025	0.131	-0.026	-0.039	-0.037
J.H.	0.475	-0.149	0.008	-0.339	0.329	-0.012	0.031	-0.052	0.116	0.075	-0.050	0.086
J.P.	0.908	-0.267	-0.121	-0.468	0.215	0.024	0.019	0.080	0.260	0.023	-0.035	0.144
L.H.	0.856	-0.197	0.001	-0.738	0.467	-0.041	0.011	-0.247	0.440	0.023	-0.065	-0.040
L.S.	0.798	-0.251	-0.025	-0.679	0.456	0.032	0.035	-0.125	1.130	0.036	0.028	0.092
M.T.	0.884	-0.320	-0.132	-0.865	0.206	0.067	0.069	-0.048	0.243	0.116	-0.056	0.020
S.R.	0.741	-0.276	0.114	-0.777	0.014	-0.023	0.034	-0.021	-0.198	0.232	-0.109	0.282
Mean	0.796	-0.250	-0.015	-0.694	0.195	0.047	0.008	-0.017	0.277	0.064	-0.053	-0.024
S.D.	0.169	0.073	0.094	0.184	0.255	0.071	0.072	0.196	0.333	0.081	0.045	0.175

Table 7

Linear Displacement of Hip (Meters)

Subject	Down Sweep				In Sweep				Up Sweep			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	1.116	-0.106	-0.041	-1.112	0.183	-0.047	-0.030	-0.184	0.980	-0.024	-0.170	-0.668
A.K.	0.952	-0.160	-0.136	-0.889	0.229	-0.024	-0.034	-0.218	0.325	0.027	0.011	-0.224
C.C.	0.918	-0.171	-0.192	-0.921	0.335	0.019	-0.089	-0.292	0.344	-0.050	-0.110	-0.330
C.L.	0.565	-0.096	-0.125	-0.561	0.238	-0.040	-0.031	-0.233	0.616	0.003	-0.033	-0.543
H.K.	1.014	-0.197	-0.071	-0.952	0.353	-0.088	-0.074	-0.242	0.325	0.019	-0.082	-0.129
J.G.	0.577	-0.120	-0.093	-0.547	0.508	-0.083	-0.110	-0.438	0.191	0.143	-0.030	-0.079
J.H.	0.446	-0.089	-0.069	-0.398	0.311	-0.037	-0.054	-0.277	0.344	0.019	-0.032	-0.137
J.P.	0.870	-0.147	-0.140	-0.712	0.326	-0.021	-0.035	-0.145	0.263	0.049	-0.010	0.026
L.H.	0.782	-0.074	-0.079	-0.716	0.449	-0.061	-0.012	-0.389	0.589	0.007	-0.016	-0.370
L.S.	0.929	-0.136	-0.067	-0.869	0.383	-0.029	-0.024	-0.307	0.419	0.010	-0.023	-0.244
M.T.	0.566	-0.135	-0.142	-1.073	0.280	0.026	-0.025	0.283	0.455	0.022	-0.063	-0.317
S.R.	0.698	-0.111	-0.137	-0.697	0.373	0.020	-0.023	-0.334	0.280	-0.005	-0.057	-0.252
Mean	0.786	-0.129	-0.108	-0.787	0.331	-0.024	-0.045	-0.227	0.428	0.010	-0.051	-0.272
S.D.	0.229	0.042	0.047	0.230	0.104	0.030	0.032	0.095	0.246	0.031	0.058	0.226

APPENDIX I

Linear Velocities

Tables 8 - 11

Table 8

Linear Velocity of the finger (Meters/Second)

Subject	Start of the downsweep			Start of the insweep			Start of the upsweep			Finish of the upsweep		
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	4.20	0.81	-1.02	4.40	-0.91	-1.25	-1.03	1.86	-0.49	-0.34	0.51	0.79
A.K.	2.42	-1.51	0.47	2.89	-1.55	-0.22	-1.72	2.32	-2.99	0.90	0.87	3.25
C.C.	3.35	-1.64	-0.15	3.73	-4.51	0.34	-1.20	4.68	-2.32	2.04	0.45	3.12
C.L.	2.37	-1.37	-0.04	2.74	1.07	-1.34	-1.53	2.30	-7.02	1.40	0.31	7.17
H.K.	2.22	-1.15	-1.39	2.86	-0.10	-1.80	0.64	1.92	-3.04	0.47	1.41	3.38
J.P.	0.52	0.30	-1.25	1.39	-0.34	-1.68	-1.65	2.09	-2.81	0.49	1.41	3.18
J.G.	3.64	-1.60	-0.67	4.03	0.31	-2.76	0.26	2.79	-2.62	1.22	1.35	3.19
J.H.	2.85	-0.51	-0.57	2.95	-1.51	-1.41	-0.34	2.09	-1.21	-0.24	0.09	1.24
L.S.	3.85	-1.58	-1.30	4.32	-1.65	-0.83	-0.15	1.85	-0.54	-0.09	0.70	0.89
L.H.	3.56	-2.75	-1.19	4.65	-3.50	-0.80	-0.72	3.66	-1.31	-0.44	0.11	1.39
M.T.	2.28	-1.22	-0.47	2.63	-1.18	-0.84	-1.20	1.88	-2.30	0.07	2.15	3.15
S.R.	2.28	-0.52	0.40	2.38	-0.10	-1.99	-0.16	2.00	-0.85	0.59	0.22	1.06
Mean	2.79	-1.06	-0.60	3.25	-1.16	-1.21	-0.73	2.45	-2.29	0.51	0.80	2.65
S.D.	1.00	0.95	0.66	0.98	1.58	0.83	0.78	0.87	1.77	0.77	0.65	1.78

Table 9

Linear Velocity of the elbow (Meters/Second)

Start of the downsweep				Start of the insweep				Start of the upsweep				Finish of the upsweep				
Subject	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	6.79	-1.11	-1.38	7.01	0.57	-0.41	0.61	0.92	-1.07	-0.14	0.17	1.09	0.70	1.30	-1.32	1.98
A.K.	3.98	-1.81	-0.11	4.33	-1.26	0.60	0.22	1.42	-0.90	1.74	-0.76	2.10	-0.87	1.46	0.51	1.77
C.C.	0.41	-1.13	-0.18	1.22	-2.48	0.54	1.17	2.80	-2.20	2.19	-0.54	3.15	0.79	0.93	-1.08	1.63
C.L.	1.05	-1.03	-1.33	1.99	0.26	-0.72	-0.20	0.99	-1.44	0.97	1.21	2.11	-0.38	0.94	-0.62	1.19
H.K.	4.15	-1.68	-1.07	4.60	0.18	-0.26	1.21	1.25	-0.99	0.79	-0.68	1.44	-0.05	0.68	-0.64	0.93
J.P.	4.42	-2.66	-1.23	5.04	0.91	-1.40	0.13	1.67	-0.92	1.85	0.51	2.13	0.74	0.57	0.13	0.94
J.G.	2.21	-1.35	-0.58	2.66	0.59	-0.31	1.09	1.28	0.39	0.65	-0.89	1.17	1.15	1.25	-1.30	2.14
J.H.	1.03	-3.13	-0.19	3.30	0.23	-0.78	0.57	1.00	-0.85	1.08	-0.26	1.39	-0.62	3.10	-1.32	3.43
L.S.	1.87	-1.07	-0.69	2.26	-0.06	-0.35	-0.06	0.36	-1.51	1.64	0.34	2.26	1.11	1.37	-0.82	1.94
L.H.	1.48	-0.81	0.36	1.72	0.80	-0.78	0.40	1.18	-0.74	0.83	-0.22	1.13	0.59	1.19	-0.62	1.47
M.T.	2.82	-1.92	-0.85	3.52	-0.43	-0.87	-0.07	0.97	-1.12	2.22	1.30	2.81	1.37	0.65	-0.88	1.75
S.R.	0.62	-0.54	-0.05	0.83	0.81	-0.32	0.24	1.05	-1.52	0.96	-0.08	1.80	-2.01	1.22	-0.73	2.45
Mean	2.57	-1.52	-0.61	3.20	0.01	-0.42	0.44	1.24	-1.07	1.23	0.01	1.88	0.21	1.22	-0.72	1.80
S.D.	1.92	0.76	0.57	1.80	0.99	0.57	0.50	0.58	0.61	0.70	0.73	0.67	1.01	0.66	0.56	0.69

Table 10

Linear Velocity of the shoulder (Meters/Second)

Subject	Start of the downsweep				Start of the insweep				Start of the upsweep				Finish of the upsweep			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	5.82	2.90	-0.52	5.85	1.79	-0.23	-0.16	1.81	1.38	0.15	0.07	1.35	1.78	-0.10	-0.30	1.81
A.K.	0.64	-0.14	0.13	0.67	1.94	0.86	-0.05	2.12	0.68	0.15	0.12	0.71	2.20	-1.02	-0.75	2.53
C.C.	-1.77	0.05	1.29	2.19	1.49	0.33	0.13	1.53	-0.02	0.71	-0.10	0.72	1.40	-0.29	-0.67	1.58
C.L.	0.51	-0.46	0.53	0.87	1.91	-0.23	-0.17	1.93	1.46	0.78	0.21	1.67	1.62	-0.16	-0.48	1.70
H.K.	1.65	-0.56	-0.71	1.88	1.07	-0.23	0.22	1.11	1.49	0.33	0.03	1.53	1.93	-0.48	-0.01	1.99
J.P.	1.54	-0.55	0.03	1.63	1.65	-0.33	-0.34	1.71	2.12	0.25	-0.20	2.14	0.71	0.27	0.15	0.77
J.G.	2.36	-0.38	-0.27	2.46	1.27	0.13	-0.06	1.28	1.16	-0.13	-0.34	1.22	1.71	-0.42	-0.45	1.82
J.H.	1.54	-0.79	-0.27	1.75	2.37	-0.29	0.24	2.40	0.67	0.74	0.07	1.00	2.74	-0.83	-1.26	3.13
L.S.	1.16	-0.82	-0.17	1.43	1.57	-0.15	-0.01	1.58	1.81	0.37	0.11	1.85	2.66	-0.02	0.25	2.67
L.H.	0.32	0.45	0.00	0.56	1.97	-0.27	-0.04	1.99	1.63	0.06	0.01	1.63	3.27	-0.71	-0.70	3.42
M.T.	1.05	-0.66	0.15	1.25	1.76	-0.45	-0.02	1.81	1.02	0.59	0.21	1.20	1.29	-0.34	-0.76	1.53
S.R.	-0.49	-0.20	0.19	0.56	1.00	-0.24	0.04	1.03	2.86	0.02	-0.01	2.69	0.74	-0.02	0.19	0.76
Mean	1.19	-0.10	0.03	1.76	1.65	-0.09	-0.02	1.69	1.36	0.33	0.01	1.47	1.84	-0.34	-0.40	1.98
S.D.	1.82	1.01	0.52	1.44	0.40	0.37	0.16	0.41	0.75	0.31	0.16	0.58	0.78	0.37	0.47	0.83

Table 11

Linear Velocity of the Hip (Meters/Second)

Start of the downsweep				Start of the insweep				Start of the upsweep				Finish of the upsweep				
Subject	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
A.G.	-5.05	3.87	-0.58	6.39	1.62	-0.36	-0.04	1.66	2.15	-0.37	-0.53	2.24	0.62	-0.07	-0.19	0.65
A.K.	3.73	-0.67	0.21	1.80	2.33	-0.30	-0.33	2.37	1.25	0.15	-0.29	1.29	2.54	0.20	0.49	2.59
C.C.	1.59	-0.74	-0.33	1.78	2.46	0.21	-0.72	2.57	2.29	-0.28	-0.73	2.42	3.76	-0.56	-1.31	4.02
C.L.	2.32	-0.37	-0.08	2.13	1.22	-0.27	-0.30	1.23	2.33	-0.12	-0.18	2.34	2.56	0.45	0.38	2.63
H.K.	0.68	-0.19	0.58	0.91	1.24	0.11	-0.27	1.27	1.31	0.34	-0.01	1.35	2.32	-0.34	-0.76	2.46
J.P.	0.82	-0.60	-0.12	-0.16	-0.30	0.01	-0.21	-0.13	-0.32	0.18	0.37	-0.13	-0.32	0.18	0.37	-0.13
J.G.	1.36	-0.32	-0.15	4.03	2.29	-0.60	-0.86	2.52	1.99	0.28	-0.34	2.04	1.85	0.64	-0.19	1.97
J.H.	0.33	-0.12	-0.04	0.35	1.76	0.25	-0.22	1.79	1.67	0.00	-0.24	1.38	1.89	0.16	0.07	1.90
L.S.	3.86	-1.13	0.04	4.03	1.50	-0.13	-0.25	1.54	2.27	0.09	-0.08	2.27	0.47	0.29	0.01	0.55
L.H.	2.23	-0.49	0.00	2.28	1.71	-0.39	-0.20	1.76	1.67	-0.07	-0.17	1.68	1.29	0.32	-0.14	1.34
M.T.	0.20	-0.21	0.07	0.30	1.14	-0.05	-0.07	1.02	2.29	0.18	-0.40	2.72	1.30	-0.02	-0.26	1.32
S.R.	0.46	-0.26	0.21	0.57	2.72	-0.39	-0.35	2.77	1.90	-0.13	-0.37	1.94	0.75	-0.06	-0.46	0.88
Mean	1.04	-0.10	-0.02	2.03	1.64	-0.16	-0.32	1.70	1.73	0.02	-0.25	1.80	1.59	0.10	-0.17	1.68
S.D.	2.29	1.28	0.29	1.93	0.80	0.27	0.24	0.81	0.75	0.22	0.28	0.76	1.13	0.33	0.51	1.15

APPENDIX J

Maximum, Minimum, Mean, and Resultant
of Finger and Hip Velocities

Tables 12 - 13

Table 12

Resultant velocity of finger (Meters/Second)

Subject	Min	Mean	S.D.	Max
A.G.	-1.26	0.43	1.15	3.00
A.K.	1.32	2.77	0.93	4.74
C.C.	2.36	3.39	0.70	4.95
C.L.	2.00	3.67	1.35	7.25
H.K.	1.22	2.65	0.96	4.62
J.G.	1.75	2.59	0.61	4.03
J.H.	1.16	2.63	0.89	4.50
J.P.	1.35	2.61	0.62	3.84
L.H.	1.22	2.53	0.86	4.65
L.S.	0.89	2.91	1.09	4.78
M.T.	0.98	2.45	0.94	4.42
S.R.	1.06	2.28	0.77	4.12
Mean	1.17	2.58	0.90	4.57
S.D.	0.88	0.78	0.22	1.00

Table 13

Velocity of Hip (X) (Meters/Second)

Subject	Min	Mean	S.D.	Max
A.G.	-5.05	2.08	1.65	6.46
A.K.	1.25	2.08	0.56	3.73
C.C.	1.59	2.46	0.51	3.76
C.L.	1.23	1.95	0.54	3.29
H.K.	0.68	1.74	0.60	3.49
J.G.	1.08	1.74	0.34	2.34
J.H.	0.33	1.56	0.40	2.04
J.P.	0.71	1.70	0.31	2.12
L.H.	1.06	1.82	0.63	3.62
L.S.	0.47	2.08	0.61	3.86
M.T.	-0.08	1.36	7.83	2.90
S.R.	0.45	1.40	0.63	12.72
Mean	0.31	1.83	1.22	3.36
S.D.	1.75	0.32	2.11	1.17

APPENDIX K

Graphs of X, Y, Z, and Resultant Velocities

Figures 22 - 33

Figure 22. Subject A. G.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 23. Subject A. K.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 24. Subject C. C.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

C. L. XYZ Velocity

C. L. Resultant Velocity

Figure 25. Subject C. L.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

H. K.. XYZ Velocity

H. K. Resultant Velocity

Figure 26. Subject H. K.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 27. Subject J. G.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 28. Subject J. H.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 29. Subject J. P.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 30. Subject L. H.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

L. S. XYZ Velocity

L. S. Resultant Velocity

Figure 31. Subject L. S.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

Figure 32. Subject M. T.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

S. R. XYZ Velocity

S. R.. Resultant Velocity

Figure 33. Subject S. R.'s graph of middle finger showing X, Y, Z, and Resultant Velocities.

APPENDIX L
Graphs of Hip Velocity
Figures 34 - 45

Figure 34. Subject A. G.'s hip velocity in X.

Figure 35. Subject A. K.'s hip velocity in X.

Figure 36. Subject C. C.'s hip velocity in X.

Figure 37. Subject C. L.'s hip velocity in X.

Figure 38. Subject H. K.'s hip velocity in X.

Figure 39. Subject J. G.'s hip velocity in X.

Figure 40. Subject J. H.'s hip velocity in X.

Figure 41. Subject J. P.'s hip velocity in X.

Figure 42. Subject L. H.'s hip velocity in X.

Figure 43. Subject L. S.'s hip velocity in X.

Figure 44. Subject M. T.'s hip velocity in X.

Figure 45. Subject S. R.'s hip velocity in X.

Figure 46. Hip Velocity in X of Robin Leemy, Marybeth Linzmeier, and Tom Jager.

APPENDIX M

Maximum, Minimum, Mean, and Resultant of Finger Acceleration

Table 14

Table 14

Acceleration of finger (Meters/Second/Second)

Subject	Min	Mean	S.D.	Max
A.G.				
A.K.	4.67	26.64	13.05	53.52
C.C.	3.62	28.13	14.85	53.23
C.L.	9.37	38.21	24.31	95.07
H.K.	3.97	24.25	11.00	47.84
J.G.	7.93	24.42	6.49	42.35
J.H.	6.55	25.10	11.51	52.80
J.P.	5.02	23.17	9.07	39.13
L.H.	3.41	27.43	10.69	56.17
L.S.	2.55	25.15	12.87	55.33
M.T.	3.15	24.69	13.52	57.66
S.R.	3.29	24.03	12.75	63.39
Mean	4.87	26.57	12.74	56.04
S.D.	2.19	4.14	4.48	14.65

APPENDIX N

Percentage of Time During Sweeps

Table 15

Table 15

Percentage of time during sweeps

Subject	Down	In	Up	Total time(s)
A.G.	53.45	12.07	34.48	0.97
A.K.	32.22	15.56	22.22	0.75
C.C.	32.50	20.00	17.50	0.66
C.L.	50.00	17.39	32.61	0.77
H.K.	61.02	18.64	20.34	0.99
J.G.	46.67	40.00	13.33	0.75
J.H.	53.49	20.93	25.58	0.71
J.P.	56.62	21.15	19.23	0.87
L.H.	50.82	21.31	27.87	1.02
L.S.	52.94	23.53	23.53	0.85
M.T.	55.17	20.69	24.14	0.97
S.R.	53.45	24.14	22.41	0.97
Mean	49.863	21.284	23.603	0.86
S.D.	8.896	6.7787	6.0131	0.12

APPENDIX O
Angular Displacement
Tables 16 - 19

Table 16

Angular displacement at the start of the downsweep.

Angles are in degrees.

Subject	Wrist	Elbow	Shoulder	Hand	Forearm
A.G.	172.12	135.15	158.82	49.32	57.16
A.K.	169.61	152.47	154.83	78.52	77.16
C.C.	176.86	166.29	166.20	76.07	75.26
C.L.	177.47	141.30	138.36	61.57	63.56
H.K.	171.91	114.08	145.05	52.89	59.34
J.G.	172.67	151.30	156.81	58.93	65.29
J.H.	121.91	132.20	154.05	0.99	57.07
J.P.	176.99	119.95	143.92	64.17	61.36
L.H.	178.73	139.67	162.61	59.82	60.99
L.S.	167.69	141.52	163.47	66.16	60.70
M.T.	159.16	144.54	151.50	58.18	48.68
S.R.	161.28	161.21	160.84	65.74	64.59
Mean	167.20	141.64	154.71	57.70	62.60
S.D.	15.55	15.30	8.62	19.72	7.73

Table 17

Angular displacement at the start of the insweep.

Angles are in degrees.

Subject	Wrist	Elbow	Shoulder	Hand	Forearm
A.G.	157.68	135.34	136.93	32.78	46.31
A.K.	170.45	124.51	92.76	37.96	47.38
C.C.	135.22	145.65	120.29	3.54	35.26
C.L.	170.64	170.64	149.49	65.21	60.71
H.K.	175.40	138.36	115.26	58.09	61.77
J.G.	152.80	160.54	144.36	48.23	74.62
J.H.	172.41	156.46	140.43	68.68	64.09
J.P.	158.50	142.51	134.79	50.81	41.52
L.H.	157.71	141.07	152.61	39.57	43.71
L.S.	176.93	173.92	146.39	60.36	57.64
M.T.	144.10	120.80	119.72	39.67	37.45
S.R.	175.39	157.34	127.71	57.16	58.04
Mean	162.27	147.26	131.73	46.84	52.37
S.D.	13.51	16.85	17.37	17.85	12.13

Table 18

Angular displacement at the start of the upsweep.

Angles are in degrees.

Subject	Wrist	Elbow	Shoulder	Hand	Forearm
A.G.	171.36	106.96	101.56	33.62	33.41
A.K.	179.03	90.41	40.69	33.42	34.29
C.C.	121.12	54.56	19.62	15.68	41.54
C.L.	154.84	124.52	89.03	43.77	22.58
H.K.	173.11	78.96	45.73	33.38	28.25
J.G.	166.25	82.86	33.27	31.23	28.07
J.H.	168.88	103.21	74.91	23.44	28.89
J.P.	166.28	98.79	49.79	23.09	17.31
L.H.	172.06	105.22	41.46	6.95	11.02
L.S.	128.32	83.60	58.01	12.47	37.76
M.T.	172.45	93.92	45.93	6.54	13.41
S.R.	172.43	97.89	69.52	19.34	23.71
Mean	162.18	93.41	55.79	23.58	26.69
S.D.	18.49	17.51	23.82	11.80	9.49

Table 19

Angular displacement at the finish of the up sweep.

Angles are in degrees.

Subject	Wrist	Elbow	Shoulder	Hand	Forearm
A.G.	168.33	136.95	22.36	44.70	44.87
A.K.	165.76	106.46	17.92	20.72	56.25
C.C.	111.43	39.19	14.40	19.12	44.47
C.L.	160.94	115.62	18.55	2.74	21.74
H.K.	162.61	142.30	25.27	29.93	45.10
J.G.	148.30	117.50	25.00	12.69	18.82
J.H.	154.98	80.44	22.96	24.68	0.33
J.P.	150.16	106.98	9.31	33.03	22.28
L.H.	139.02	115.28	12.70	57.80	30.47
L.S.	169.49	94.96	12.27	20.69	14.80
M.T.	168.61	132.76	21.78	33.01	39.74
S.R.	154.28	98.18	17.92	30.74	5.53
Mean	154.49	107.22	18.37	27.49	28.70
S.D.	16.52	27.94	5.29	14.44	17.54

APPENDIX P

Displacement Correlations

Tables 20 - 22

Table 20

Linear Displacement Correlations

Finger												
Downsweep				Insweep				Upsweep				
X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	
-0.06	-0.31	0.01	-0.17	0.13	0.13	0.26	0.17	-0.03	0.23	-0.27	0.11	
Elbow												
Downsweep				Insweep				Upsweep				
X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	
-0.15	-0.20	-0.10	-0.01	-0.11	0.32	0.20	0.32	-0.20	-0.08	0.04	-0.53	
Shoulder												
Downsweep				Insweep				Upsweep				
X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	
-0.34	0.03	0.17	0.22	-0.29	0.59	-0.28	0.20	-0.01	-0.06	-0.01	-0.70	
Hip												
Downsweep				Insweep				Upsweep				
X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	
0.13	-0.20	-0.02	-0.04	-0.53	-0.21	-0.63	0.22	0.19	-0.20	-0.21	-0.17	

Table 21

Linear Velocity Correlations

	Start of Downsweep				Start of Insweep				Start of Upsweep				Finish of Upsweep			
	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R	X	Y	Z	R
Finger																
	0.13	-0.13	0.29	0.10	0.07	0.27	-0.47	0.52	0.53	0.57	0.04	0.48	0.46	-0.22	-0.26	-0.35
Elbow																
	0.09	-0.15	-0.29	0.18	-0.29	0.36	0.23	0.46	0.03	0.01	-0.28	0.06	-0.01	-0.05	0.09	-0.29
Shoulder																
	0.01	0.45	0.20	0.41	0.18	0.56	-0.37	0.18	-0.55	0.24	-0.05	-0.49	-0.10	-0.17	-0.26	-0.06
Hip																
	0.22	-0.16	-0.58	0.26	0.08	0.14	-0.30	0.06	0.17	-0.18	-0.24	0.06	0.62	-0.02	0.17	0.64

Table 22

Angular displacement correlations.

	Wrist	Elbow	Shoulder	Hand	Forearm
Start of the downsweep	0.08	0.10	-0.17	0.17	0.48
Start of the insweep	-0.45	-0.09	-0.12	-0.39	-0.10
Start of the upsweep	-0.28	-0.03	-0.22	0.62	0.35
Finish of the upsweep	-0.27	0.04	0.15	-0.43	0.50