AN ABSTRACT OF THE THESIS OF

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Title: A Kinetic and Kinematic Comparison of the Grab and Track Starts in Competitive Swimming.

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Debra J. Rose

In competitive swimming a spread in time of only 0.10, and 0.16 seconds constituted the difference between finishing second and seventh, and first and eighth, respectively, in the women's 50 yard freestyle at the 1993 NCAA Division III National Swimming & Diving Championships. Based on data collected over a period of years Maglischo (1993) noted that "improving the start can reduce race times by at least 0.10 second" (p. 544). Therefore it is beneficial to the outcome of a race to direct attention to maximizing the effectiveness of the racing start. The primary purpose of this study therefore was to compare kinetic and kinematic components of the grab and track style starts.

During the past two decades extensive kinematic research has been done using cinematography. These studies used time, velocity, displacement, and the measure of angles (i.e. at takeoff and entry) to measure the relative effectiveness of various racing starts. Conversely, there has been limited analysis of racing starts using kinetic measurements.

Four kinetic and five kinematic variables were evaluated in this study to compare the relative effectiveness of the starting techniques. Ten female varsity swimmers, who had used both starts interchangeably in competition, were selected for this study. Force components were obtained directly from a Kistler force platform. Block time, horizontal and vertical impulse, and average horizontal and vertical force values were obtained in subsequent analysis of the Force-time data. Each subject was videotaped as she executed three trials of each start. The video data were digitized and then analyzed using two dimensional video analysis techniques.

The type of start technique used on each trial was randomly ordered. Kinematic variables of horizontal and vertical displacement of the center of mass, average horizontal velocity and vertical velocity were also obtained from the video data in order to determine which of the two starting techniques (ie. grab vs. track) was the most effective.

2x10 (starting technique x subject) repeated measures Analyses of Variance indicated significant differences ($p < 0.01$) between the starting styles for five of the nine dependent variables measured which provided support for the original contention that the track style start was the more effective of the two racing start techniques investigated. The results of this study provide support to the empirical and observational findings of earlier researchers.

A Kinetic and Kinematic Comparison of the Grab and Track Starts in Competitive Swimming

by

Cheryl A. Juergens

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Cheryl A. Juergens, Author

This thesis is
dedicated to the loving
memory of Ann O. Spaulding, C.S.B.
and Florence L. Shuff, C.S.

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A Kinetic and Kinematic Comparison of the Grab and Track Starts in Competitive Swimming

CHAPTER I
INTRODUCTION

Introduction to the Study

Faster racing start performances can provide a swimmer with a significant advantage over competitors with slower starting performances. Although the racing start is only one aspect of a competitive swimming event, the attention given to developing the most effective racing start may significantly affect the outcome of a swimming race.

Several studies (e.g., Hunt, 1976; Maglischo, 1982; Miller, Hay, & Wilson, 1984) have determined that a correctly performed racing start may be an important contributing factor to the outcome of a swimming race, especially in the sprint and middle distance events. Maglischo (1993) concluded that the time spent starting accounts for 25 percent of 25 (yards/meters) events, 10 percent of 50 events and 5 percent of 100 events. It has also been noted that the difference in the outcome of a race can be as little as 0.01 seconds (Miller, J., Hay, J.E., & Wilson, B.D., 1984) and that improved starting performances have decreased racing times by as little as 0.01 to as much as 0.10 second (Maglischo, 1982 & 1993). Maglischo (1993) further suggests that a serious flaw in training is that athletes spend too little time perfecting racing starts.

Additional support for the importance of perfecting the racing start technique is provided in the 1993 and 1994 NCAA (National Collegiate Athletic Association) National Swimming and Diving Championship results reported in The NCAA News and in Swimming World. At the 1993 Division III Nationals less than 0.2 seconds separated the top finishers in the women's 50 yard freestyle event. A spread in time of only 0.10 seconds constituted the difference between second and seventh place, 0.16 seconds separated the first through eighth and ninth through eleventh places, and 0.18 seconds separated twelfth through sixteenth places.

At the 1994 NCAA Division I National Championships, differences of only fractions of a second again separated the top finishers. In the women's 50 yard freestyle 0.14 seconds separated the fourth through seventh and ninth through thirteenth finishers. In the mens 50 yard freestyle 0.19 seconds separated first through third and sixth through eighth places. At the same championship, differences of less than 0.10 seconds separated many finishers: in the men's 50 and the women's 500 freestyle only 0.05 seconds separated the ninth through twelfth and the first and second place finishers, respectively.

Review of the above 1993 and 1994 NCAA championship results, where differences of only hundredths of a second significantly affected the outcome of a race, in conjunction with research findings illustrating the importance of developing an effective starting technique, further suggests the need to determine which type of racing start technique is the most effective.

The two most popular swimming racing starts in current use are the grab and track starts, though the former start is preferred by a majority of swimmers. (A more complete description of these two start techniques is provided in the Terminology section of this chapter.)

The grab start was first introduced to the swimming world in the mid-1960's, and by the early 1970's its increasing popularity was apparent. In fact, Lowell (1975) noted that all 50 yard freestyle finalists at the 1971-74 NCAA National Swimming & Diving Championships used the grab style starting technique.

The grab start's initial popularity was based almost entirely upon untested hypotheses, visual observations, and individual preference. Many questions concerning the performance advantages of the grab style remained unanswered.

These questions prompted coaches and researchers to design kinematic studies to determine which starting technique was superior. Cinematographical techniques were primarily used to compare the conventional style starts (conventional, conventional backward-forward armswing, conventional circular armswing) with the grab style start. In a majority of these studies, grab start performances were determined to be significantly faster than the earlier conventional techniques when a number of selected kinematic variables such as block time, time to a given distance, and velocity at takeoff were compared (e.g., Winters, 1968; Roffer, 1971; Havriluk, 1972; McCutchan, 1973; Lowell, 1975; Gibson & Holt, 1976; Havriluk, 1979).

Researchers further observed, empirically, that increased stability could be achieved when performing the grab start due to the hands also being in contact with the starting block. This starting feature also enabled the swimmer to move the center of mass (CM) much further forward toward the front edge of the starting block than earlier starting techniques (Lowell, 1975).

The most recent racing start technique to appear in competitive swimming is the track start. Although this method was originally presented for consideration in the early 1970's, only in the last 8 to 10 years has the track style start begun to achieve popularity.

When Fitzgerald (1973) first experimented with the track technique he determined from visual observation that swimmers using the track starting style entered the water in less time than swimmers using the conventional or grab style techniques. Fitzgerald subsequently recommended that the track style start be used by all swimmers, and especially those athletes competing in sprint events.

One apparent advantage of the track start technique was the wider base of support, obtained by positioning the feet in a forward-backward stance (or track position). This increased the stability of the track technique when compared to the conventional and grab starting styles. Several researchers, including Fitzgerald, agreed that the increased stability was due to the track stance, which allowed the CM of the body to be positioned much lower than in the earlier starting techniques (e.g., Ayalon, Van Gheluwe & Kanitz, 1975; Nelson & Pike, 1977; Counsilman, 1988).

LaRue (1986) conducted a study to determine the optimal distance between the front and rear foot for track start performances used in competitive swimming. A running starting block was mounted onto a swimming starting block and performances were timed to a five meter distance. LaRue found that swimmers using the track start with a medium stance (approximately 16-22 inches or 40-55 centimeters between the feet), reached the five meter distance in significantly less time than those swimmers who used the grab start technique. LaRue's findings on swimming track style starts supported previous analysis and results of track & field studies (Henry, 1952; Hogberg, 1962; Menely, 1968) which demonstrated that use of the medium stance resulted in faster movement times over a specified distance when compared to the movement times associated with either elongated (60-70 centimeters) or bunch (25-30 centimeters) stance positions. Seidel, Biles, Figley and Olds (1975) further noted that a medium stance enabled an athlete to combine the explosive, powerful advantage of the bunch start with the increased stability obtained from the elongated stance while also minimizing the corresponding disadvantages of limited stability and lack of explosive power.

Subsequent research by Ayalon, Gheluwe and Kanitz (1975) found that swimmers performing the track starting style left the starting block in less time and demonstrated significantly lower movement times to a distance of four meters when compared to swimmers who used the grab technique. Hunt (1976) found that the mean time to water was 0.066 seconds faster when a track style start was used as opposed to the grab technique, which benefitted 22 of the 27 subjects (the difference was not, however, statistically significant). Kirner, Bock and Welch (1989) investigated the effectiveness of the grab and track style starts using two different water entry methods, the hole and shallow entry. They concluded that use of the track style starting technique, combined with a shallow dive (or flat entry), resulted in the shortest times to water entry when compared to the other three combinations.

In a study designed to measure the forces exerted by the hands during a grab style start, Cavanagh, Palmgren and Kerr (1975) found that the force produced by the hands did not contribute significantly to the production of forward horizontal movement. In fact, the added contact of the hands with the starting block generated no force in the desired direction. The authors concluded that in a grab start performance the hands contacting the starting block merely served as a "brace" (p.43-50).

Hay (1985) noted that the Force-time relationship of impulse and momentum played an important role in several sports skills, which included racing starts used in swimming and running. Kreighbaum & Barthels (1985) stated that in starting performances where the goal is to leave the starting block in the shortest amount of time, the CM of the body should be positioned as far forward as possible and in the line of desired motion. It was further noted that when balanced in such a position little horizontal impulse was needed to initiate movement.

Several researchers have identified additional advantages and have advocated the importance of optimizing horizontal velocity and horizontal impulse in racing start performances (Payne & Blader, 1971; Hay & Guimaraes, 1983; Ayalon et al., 1975). From these findings it would appear that the ideal racing start would be one in which the swimmer could leave the starting block in the least amount of time and yet produce the optimal amount of horizontal impulse.

Havriluk (1979) investigated the Force-time relationship and used the impulse-momentum equation to predict the outcome of a racing start performance. He predicted that a decrease in the variable of time (a shorter takeoff time) would lead to decreased velocity at takeoff. Havriluk also deduced that the inverse case would be true if the variable of time was increased. In this case the velocity at takeoff would also increase. These both seem like logical deductions, however, in Havriluk's example the only element varied is time. What if the variable of time were decreased *and* the velocity increased (as a direct result of greater force), could a swimmer leave the block in less time and yet also attain a greater takeoff velocity? This question remains to be answered.

Research comparing the kinetic and kinematic components among racing start performances deserves further investigation. It was the primary purpose of this study therefore to extend the knowledge pertaining to the kinetic, Force-time components associated with performances of the grab and track style racing starts, and to further investigate the kinematics associated with each respective style.

Purpose of the Study

A kinetic and kinematic comparison of grab and track start performances used in competitive swimming was conducted to determine if any significant differences existed between the two starting techniques with respect to the effectiveness of each starting style.

The six kinetic variables selected for this investigation were: 1) horizontal impulse (YI), 2) vertical impulse (ZI), 3) average horizontal force (AVYF), 4) average vertical force (AVZF), 5) peak horizontal force (PYF), and 6) peak vertical force (PZF).

The seven kinematic variables of interest were: 1) block time (BT), 2) horizontal displacement of the Center of Mass (CM) from starting position to water entry (YDCM), 3) vertical displacement of the CM from starting position to water entry (ZDCM), 4) horizontal velocity of CM at takeoff (YV), 5) vertical velocity of CM at takeoff (ZV), 6) reaction time (RT) and 7) movement time (MT).

Research Hypotheses

Researchers who have compared the kinetic and kinematic components of grab and track style racing start performances, found track start performances to result in significantly faster takeoff performances and, in some instances, shorter times to water entry when compared to grab start performances. Based upon these research findings and personal observation of racing start performances as a swimming coach the following hypotheses were forwarded.

Concerning the kinetic components of interest it was hypothesized that:

1. The horizontal impulse achieved during block time for track start performances will be significantly greater than the values achieved for performances using the grab style start.
2. The vertical impulse achieved during block time for track start performances will be significantly less than the values achieved for performances using the grab style start.
3. Significantly greater average horizontal force values will be produced during block time using the track style start when compared to the grab style start.
4. Average vertical force values produced during block time will be significantly less for performances using the track style start when compared to the grab style.
5. Peak horizontal force achieved for track start performances will be greater than the values obtained for grab start performances.
6. Peak vertical force values obtained for track start performances will be less than values achieved during grab start trials.

Regarding the kinematic variables investigated, it was hypothesized that:

1. The contact time on the starting block (Block Time, BT) following the start signal will be significantly less using the track style start when compared to the grab style start.

2. The horizontal displacement of the center of mass (CM) from start position to water entry will be significantly greater in track start performances when compared to performances using the grab style start.
3. The vertical displacement of the CM from start position to water entry will be significantly less in track start performances when compared to performances using the grab style start.
4. The horizontal velocity of CM at takeoff will be significantly greater using the track style start when compared to the grab style start.
5. The vertical velocity of CM at takeoff will be significantly less in performances using the track style start when compared to the grab style start.
6. Reaction time values for track start performances will be less than the values obtained for grab start trials.
7. Movement time values achieved in track start performances will be less than the values obtained for grab start performances.

Statistical Hypotheses

TS = Track Start GS = Grab Start CM = Center of Mass

Kinetic Components:

YI = Horizontal Impulse

ZI = Vertical Impulse

AVYF = Average Horizontal Force

AVZF = Average Vertical Force

PYF = Peak Horizontal Force

PZF = Peak Vertical Force

Statistical hypotheses for kinetic variables:

1.	H_o1: TSYI = GSYI	H_a1: TSYI > GSYI
2.	H_o2: TSZI = GSZI	H_a2: TSZI < GSZI
3.	H_o3: TSAVYF = GSAVYF	H_a3: TSAVYF > GSAVYF
4.	H_o4: TSAVZF = GSAVXF	H_a4: TSAVZF < GSAVZF
5.	H_o5: TSPYF = GSPYF	H_a5: TSPYF > GSPYF
6.	H_o6: TSPZF = GSPZF	H_a6: TSPZF < GSPZF

Kinematic Components:

BT = Block Time

YDCM = Horizontal Displacement of Center of Mass

ZDCM = Vertical Displacement of Center of Mass

YV = Horizontal Velocity at takeoff

ZV = Vertical Velocity at takeoff

RT = Reaction Time

MT = Movement Time

Statistical hypotheses for kinematic variables:

1.	H_o1: TSBT = GSBT	H_a1: TSBT < GSBT
2.	H_o2: TSYDCM = GSYDCM	H_a2: TSYDCM > GSYDCM
3.	H_o3: TRZDCM = GSZDCM	H_a3: TRZDCM < GSZDCM
4.	H_o4: TSYV = GSYV	H_a4: TSYV > GSYV
5.	H_o5: TSZV = GSZV	H_a5: TSZV < GSZV
6.	H_o6: TSRT = GSRT	H_a6: TSRT < GSRT
7.	H_o7: TSMT = GSMT	H_a7: TSMT < GSMT

Limitations of the Study

1. This study was limited in application to female varsity swimmers at the high school and collegiate level.
2. Given that a sample size of only 10 subjects was used, research findings could not be generalized to the total population of female swimmers.
3. Application of performance results were limited to a non-competitive setting.
4. Force data represented the combined effect of the hands and feet in the total produced force. The force platform and interfaced instrumentation were not designed to independently measure the contributions of the hands and feet as components of force. Therefore the contribution of the arms to overall force production could not be measured due to limitations of the instrumentation.
5. A systematic error in calculating CM locations for the 10 female subjects was introduced by using the Dempster model based on male body segment parameter (BSP) data. This resulted in a consistent bias in CM locations.

Assumptions

1. The three completed trials accurately reflected each subject's optimal performance of the specified start.

2. Subjects were equally competent in their use of both starting styles.

Terminology

Air time: see flight time.

Average force: the Impulse (from first movement after start signal until takeoff) divided by the period of force application. In this study average horizontal force (AVYF) and average vertical force (AVZF) was computed.

Block time: the time measured from the electronic start signal, when the swimmer is in the ready position, until the swimmer's last body part leaves the starting block.

Bunch start: a starting technique where the athlete assumes a forward-backward stance and the distance between the two feet, measured from the toes of the front foot to the toes of the back foot, is approximately 25-30 centimeters (approximately 10-12 inches).

Center of Mass (CM): a point of a body around which all body mass is equally distributed. CM locations for each starting technique are pictured in figures 1 and 2.

Competitive swimming: a term used to signify swimming as a sport that involves racing or competition events.

Conventional start: was the more popular swimming racing start technique prior to the introduction of the grab start in the 1960's. In the conventional start the

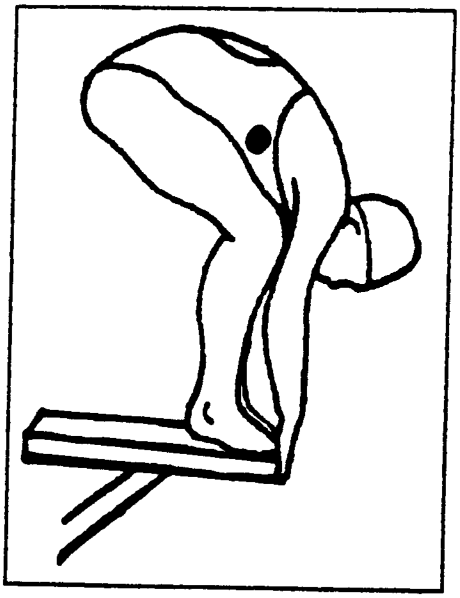

Figure 1. Center of Mass location in ready position for grab start technique.

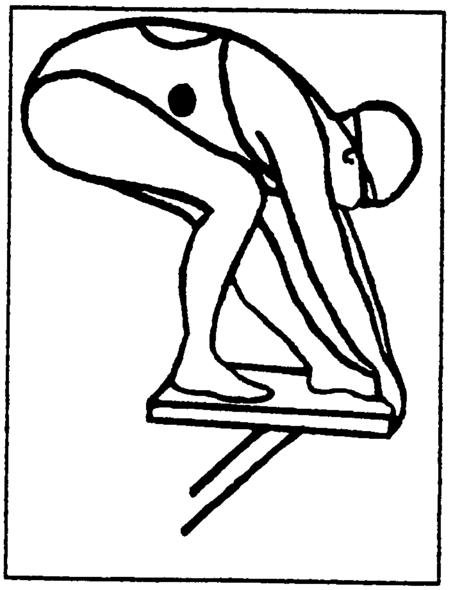

Figure 2. Center of Mass (CM) location in ready position for track start technique.

swimmer assumed a nearly standing position with the knees flexed (approx. 120 degrees) and the toes curled around the front edge of the starting block. The arms remained held at the sides and straight and were extended slightly behind the swimmer. The head maintained a chin-up position, with the eyes looking forward or to the far end of the racing pool. Upon hearing the start signal the arms were swung downward and forward, along the side of the body. When the arms began reaching outward and forward of the starting block the swimmer shifted the body weight, or the center of mass (CM) forward and began driving with the legs. The legs usually left the block together and were fully extended with the toes pointed.

Conventional backward-forward armswing start: this start is a modification to the conventional start. The main difference from the conventional start is the initial starting position where the arms remain relaxed and loosely held just in front of the swimmer's body. When the start signal is given, the arms swing backward until they reach the extended starting position used in the conventional starting technique. From this point, the start is the same as the conventional style.

Conventional circular armswing start: in this start the swimmer assumes the same starting position as with the above conventional backward-forward armswing start.

When the start signal is given, the arms begin swinging forward and upward in a circular motion. The arms continue backward and downward and then complete the circle with a final forward swing. From this point the start is identical to the above conventional start. This start is still used regularly by exchange swimmers in relay events.

Displacement of CM: the difference in position of the swimmer's body (CM) from the initial ready position until water entry. In this study displacement of CM was measured in the horizontal, or anteroposterior (YDCM), and vertical (ZDCM) directions.

Elongated start: a starting position where the athlete assumes a forward-backward stance with a distance of approximately 60-70 centimeters (approximately 24-28 inches) between the toes of the front foot and the toes of the back foot.

Flight time: the time elapsed from the point when the swimmer's feet leave the starting block until the hands enter the water.

Glide time: the time elapsed from water entry until the first swimming stroke on the water surface is taken.

Grab start: a swimming racing start technique that appeared in the 1960's. Upon the starter's command to "Take your marks" the swimmer steps to the front of the starting block and grips the front edge with the toes.

The hands may grab the starting block in one of three locations: on the lateral side of each foot (see Figure 3), between the feet (see Figure 4), or, on the side edges of the starting block (see Figure 5). The legs remain slightly flexed and the chin is tucked tightly to the chest. Prior to the start signal, the swimmer strives to maintain balance with the CM of the body as far forward, or over, the front edge of the starting block as possible. When the start signal is given, the swimmer immediately shifts to an off-balanced position and the CM is quickly moved beyond the forward edge of the starting block. The swimmer further initiates movement by simultaneously lifting the head, driving the arms forward and exerting force

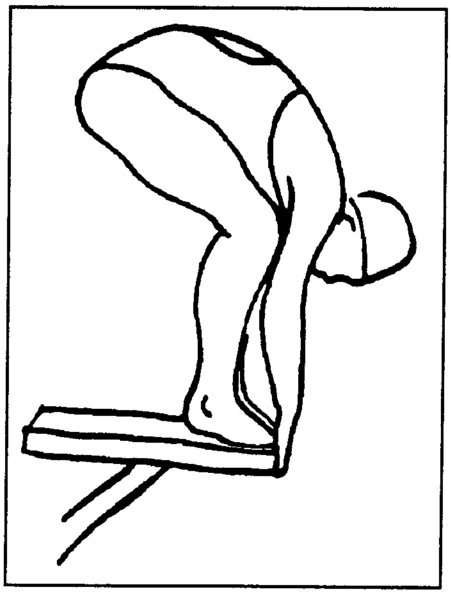

Figure 3. Grab start technique ready position, hands grasping starting block outside of feet.

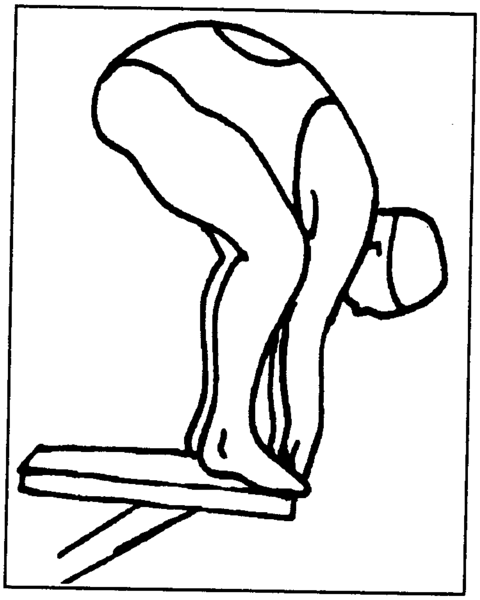

Figure 4. Grab start technique ready position, hands grasping starting block between feet.

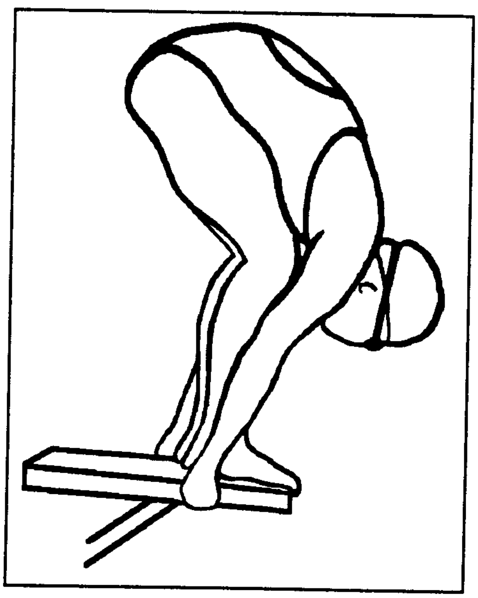

Figure 5. Grab start technique ready position, hands grasping sides of starting block.

against the starting block by a vigorous thrust from the legs and feet (see Figure 6). The legs are fully extended and the feet, the last body part contacting the starting block, leave the starting block together (see Figure 7).

Impulse (I): the integration of the F-t (Force-time) curve from start of movement which is equivalent to the area under the F-t curve and is equal to the change in momentum. In this study horizontal impulse (YI) was calculated as the measure of the area under the horizontal F-t curve (see Figure 8). In calculating vertical impulse (ZI) individual body mass was

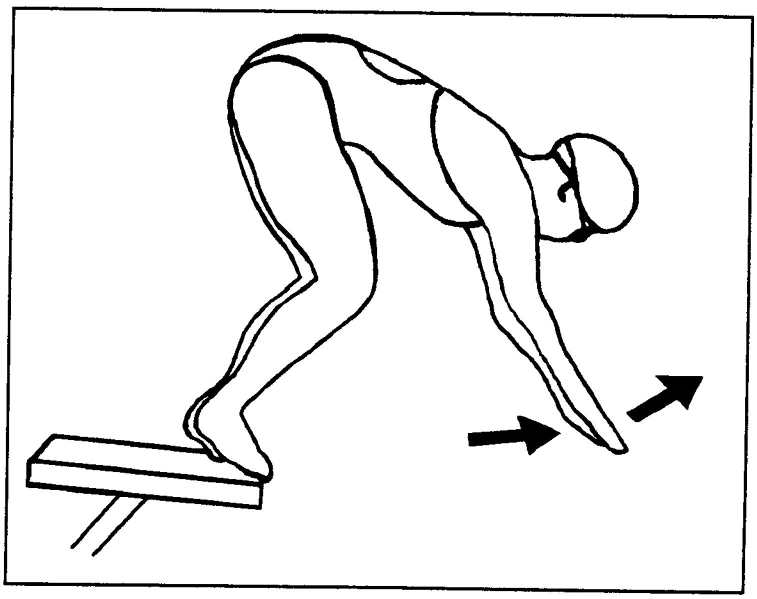

Figure 6. Grab start technique, beginning phase of forward movement.

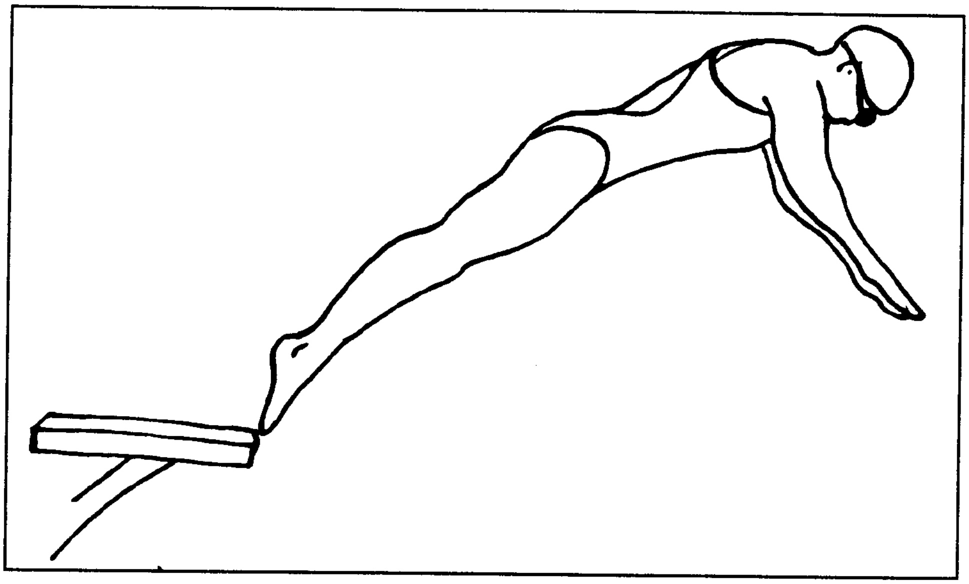

Figure 7. Grab start technique, takeoff phase.

subtracted out and a net vertical force value obtained (see Figures 8 and 9).

Kinematic(s): that branch of mechanics that describes an observed movement. Displacement, velocity and acceleration are examples of kinematic variables.

Kinetic(s): the part of mechanics that deals with the causes of movement. Horizontal force, impulse, peak force and average force are examples of kinetic variables.

Medium start: refers to the starting technique where the athlete assumes a "medium" stance (as compared with the bunch or elongated techniques) with the distance measured between the toes of the front foot and the toes of the back approximately 40-55 centimeters (approximately 16-22 inches).

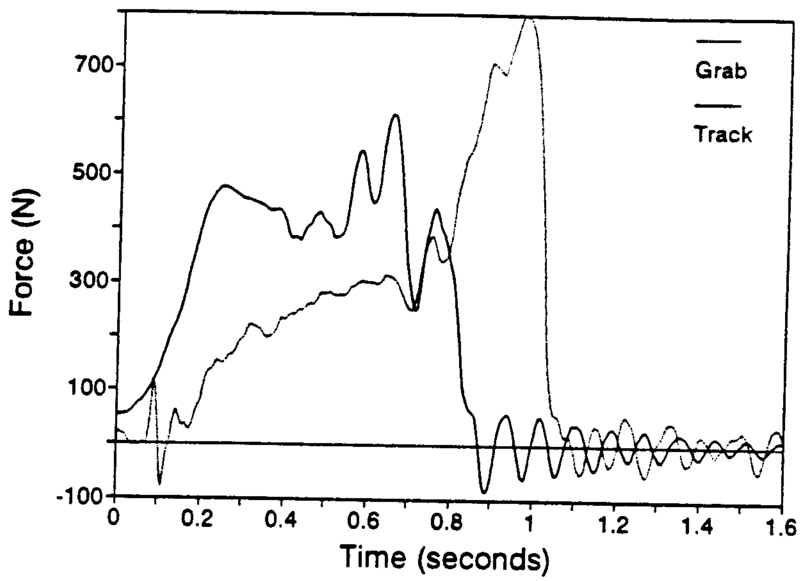

Figure 8. Typical horizontal Force-time curve for one grab and one track start trial.

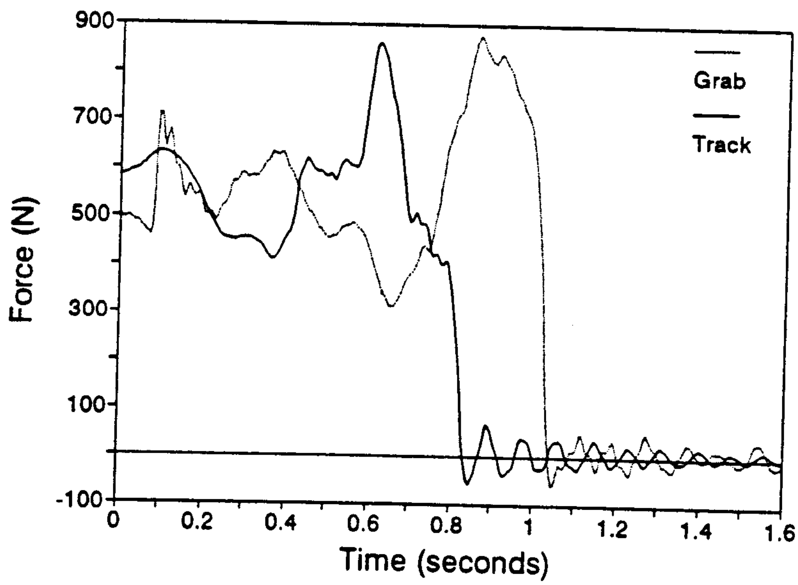

Figure 9. Typical vertical Force-time curve for one grab and one track start trial using vertical ground reaction force.

<u>Movement Time (MT):</u> the time elapsed from the initial indication of movement until the swimmer is no longer contacting the starting block. In this study MT was recorded on and derived from the force-time data.

<u>Peak force</u>: the force measurement with greatest magnitude.

<u>Reaction time</u>: the time interval from when the start signal was given until the swimmer first responded or reacted by moving (as determined from Force-time data).

<u>Takeoff velocity</u>: the measure of velocity in the vertical or horizontal direction at the point of departure from the starting block.

<u>Track start</u>: this start was originally introduced in the early 1970's but swimmers did not adopt this technique to any extent until the 1980's. Following the starter's instructions to "Take your mark" the swimmer assumes a forward-backward stance. The forward foot is placed at the front of the starting block with the toes gripping the edge of the block. The second foot is placed approximately 40-55 centimeters (approximately 16-22 inches) behind the line of the front foot. Both hands grab the front edge of the starting block, with the hand on the side of the forward leg grasping the block on the outside of the foot. The head is dropped between the arms with the chin lightly resting on the chest. The swimmer shifts the CM back from the front edge of the block and positions the hips above the heel

of the back foot. The swimmer assumes a position with the backward leg flexed while simultaneously pulling forward with the arms and straightening the front leg. In this position, the arms and legs counter balance each other as the swimmer maintains a balanced and ready position until the start signal is given (see Figure 10). When the start signal is given the swimmer simultaneously pulls forward with the arms, lifts the head, and begins driving with the legs. When the CM moves forward and beyond the starting block area, the arms drive upward and forward. The back foot leaves the starting block before the front foot (see Figure 11). The forward foot is the last body part to exert

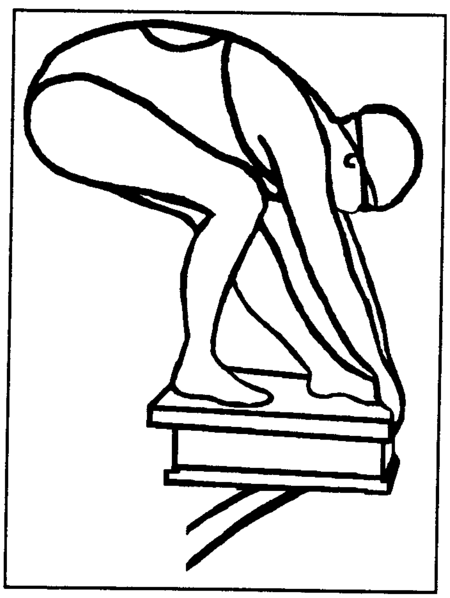

Figure 10. Track start technique ready position, feet in a forward-backward stance.

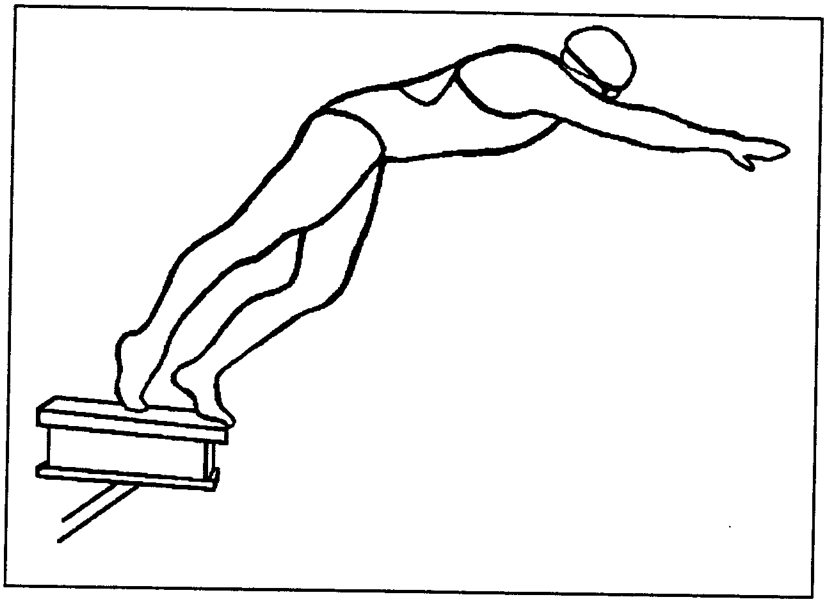

Figure 11. Track start technique, rear foot leaving starting block.

force against the starting block and to leave the starting block (see Figure 12).

Trajectory of the Center of Mass (CM): the pathway of the CM from ready position until water entry (see Figures 13 and 14).

Velocity: velocity is a vector quantity where speed and direction are specified. The average vertical velocity is obtained by dividing the total displacement (of CM) by the time elapsed to cover the distance (v = d/t). In this study average horizontal velocity (AVYV) and instantaneous vertical velocity at takeoff (ZV) are reported.

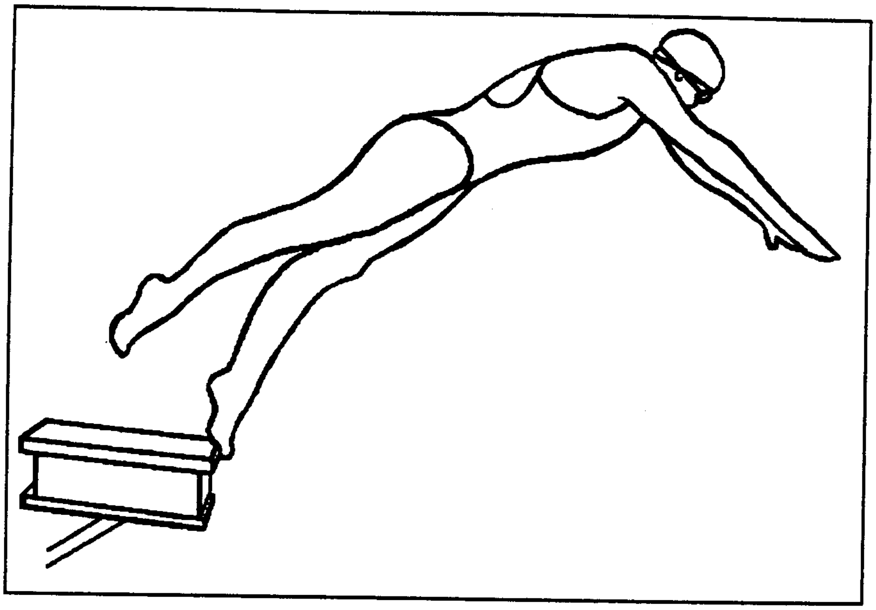

Figure 12. Track start technique takeoff phase, forward foot leaving starting block.

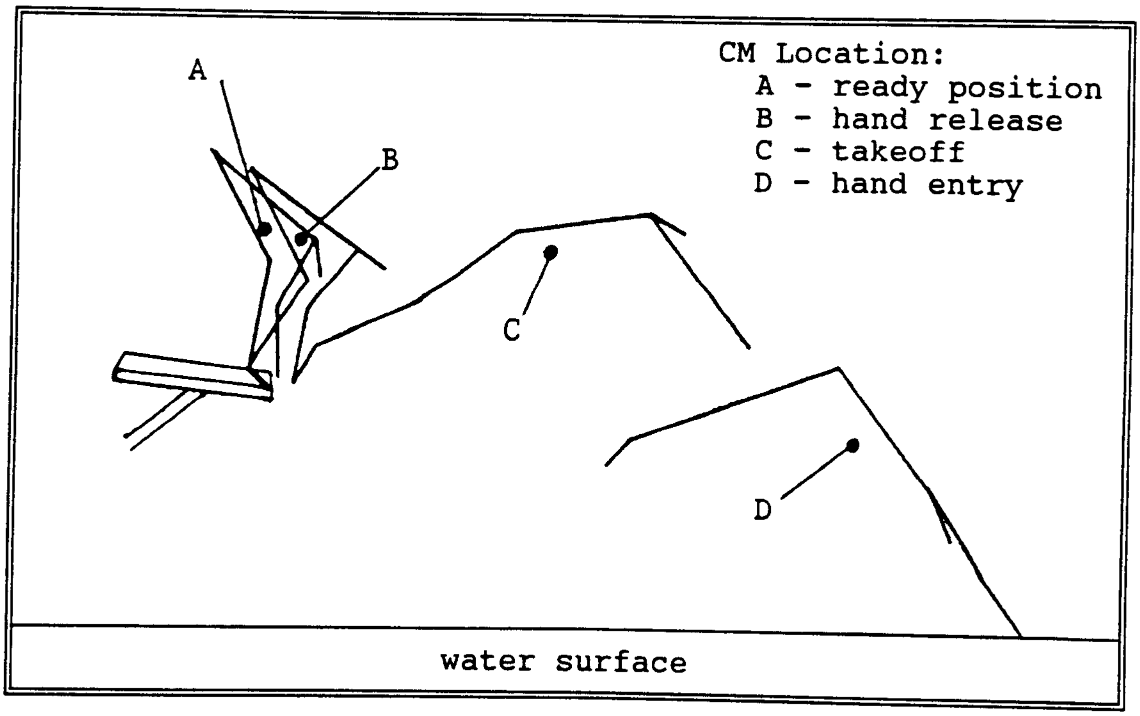

Figure 13. Trajectory of Center of Mass, Grab Start Trial.

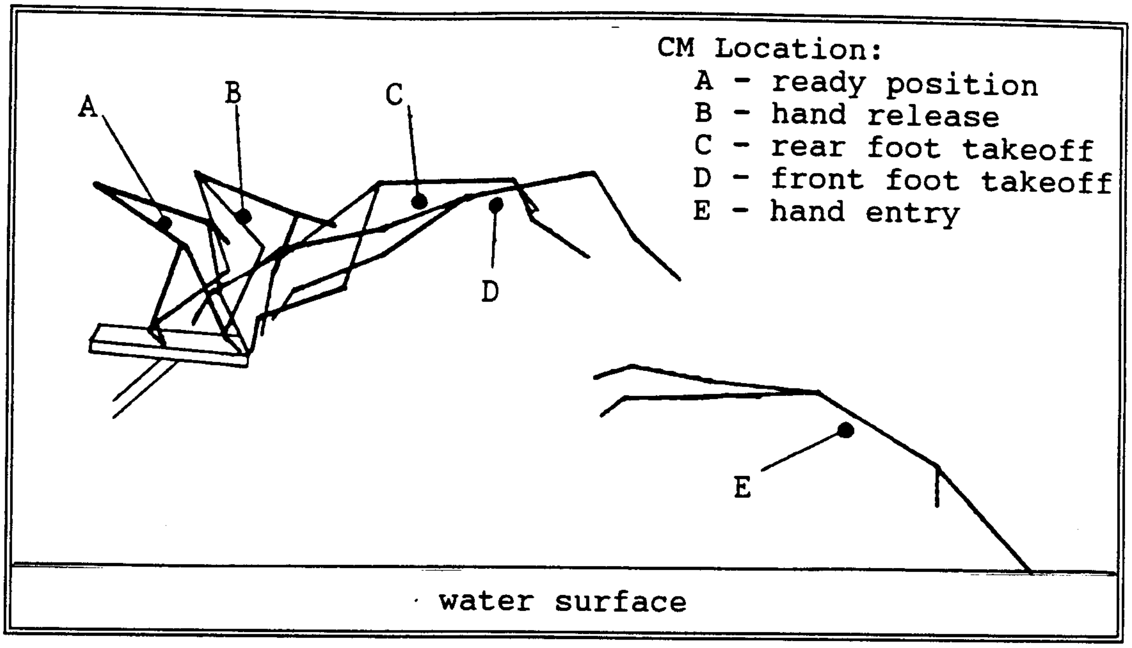

Figure 14. Trajectory of Center of Mass, Track Start Trial.

CHAPTER II
LITERATURE REVIEW

Introduction

The purpose of this research was to compare the kinetic and kinematic components in grab and track start performances, to determine any significant differences between these components in performances of these two starting techniques, and to evaluate the overall effectiveness of each starting technique. The four kinetic variables obtained during block time and of interest were: horizontal impulse, vertical impulse, average horizontal force and average vertical force.

The five kinematic variables of interest were block time, horizontal displacement of the center of mass (CM) from takeoff to water entry, vertical displacement of the center of mass (CM) from takeoff to water entry, average horizontal velocity of CM from takeoff to water entry, and vertical velocity of CM at takeoff.

The literature review is divided into the following sections: conventional starting techniques, evolution of the grab start technique, introduction of the track style racing start, research comparing current starting techniques, and a summary.

Conventional Starting Techniques

Prior to and throughout the 1960's the conventional style start was the predominant start used in speed swimming. The swimmer stood at the front of the starting block with the knees slightly flexed, feet approximately hip width apart and the toes gripping the front edge of the starting block. The trunk was positioned leaning forward with a slight bend at the waist. The arms remained straight and hyperextended behind the swimmer. Following the auditory start signal the athlete initiated forward motion with a downward and forward swing of the arms past the thighs. The arms were then swung outward, toward the water. The body followed the arms as the legs extended and applied a downward and backward force against the starting block.

The conventional style racing start was subsequently modified to include a backward and then forward armswing. This technique was referred to as the conventional backward-forward armswing start. In this method, the swimmer assumed a starting stance similar to the conventional style but with the arms extended downward in front of the body. When the start signal was given, the arms were swung backward, to a hyperextended position behind the body, and then rapidly swung forward. From the point where the arms were hyperextended behind the swimmer's body, the conventional backward-forward technique was the same as the conventional starting style.

During the 1960's the conventional start was further modified with the addition of a circular armswing. The modified style became known as the conventional circular armswing start. This start began with the body and arms in the same starting position as the conventional backward-forward armswing technique. When the start signal was given, motion began with an upward and backward circling motion of the arms. The arms continued circling backward and then downward as they moved in parallel planes to each other and remained fully extended and straight. When the arms had dropped below horizontal and had reached a hyperextended position behind the body the swimmer was in the same position as the initial stance for the conventional start. From this point, the arm action followed the downward, forward, and outward swinging motion of the conventional start. The position of the swimmer's body and the driving action of the legs against the starting block as the arms completed the forward circular armswing pattern was the same as in the earlier mentioned conventional styles.

When the circular armswing start replaced the conventional start it was believed that the circular and accelerating motion of the arms generated considerable angular momentum, particularly when the arms were stopped at the point of takeoff. It was thought that the momentum was transferred to the body and resulted in increased horizontal velocity when leaving the starting block (e.g., Counsilman, 1968). Two researchers (Maglischo & Maglischo, 1968) investigated the effectiveness of three conventional start techniques, and found the conventional circular armswing start to be more effective than the other conventional styles. They determined that performances using the conventional circular armswing start were significantly faster to a distance of 15 feet from the starting block than performances in which either the conventional or the conventional backward-forward armswing styles were used. The conventional circular armswing start is still regularly used by exchange swimmers in relay events.

Evolution of the Grab Start Technique

In 1967, Eric Hanauer introduced another starting technique to the world of competitive swimming, the grab start. In this method the swimmer stood with both feet on the front edge of the starting block and grabbed the starting block with the hands. The hands could grab the starting block in one of three locations: outside of the feet, between the feet, or on both sides of the starting block. In this study the reference to the grab start technique will refer to the first style unless otherwise stated.

Once the starting signal was given, the swimmer pulled forward with the arms, initiating forward movement of the body. The next, and perhaps most crucial, phase of the grab start occurred when the swimmer released the hands from the starting block and lifted the arms upward and outward toward the water. The toes were the last body part to leave the starting block as the legs reached full extension.

Joe Rusk, who coached at Niles North High School in Illinois, may have been the first coach to experiment with the grab start technique (Hanauer, 1967). One of Rusk's swimmers, who suffered from polio during childhood which left him with one leg weaker than the other, adopted the grab start to compensate for this condition. Hanauer (1967), after seeing the grab starting technique used, had one of his swimmers, who exhibited a tendency to false start and was typically very slow to leave the starting block, practice and use the grab technique in competition. Hanauer contended that the grab start was especially suited for his particular swimmer because it provided a more stable starting position.

Hanauer's swimmer had immediate success using the grab start and swimmers and coaches quickly adopted the grab technique. Only five years later, Hanauer (1972) noted that all 50 yard freestyle finalists at the 1971 NCAA National Championships performed the grab start. Lowell (1975) also attested to the extensive popularity of the grab start technique when he noted that from 1971-1974 all 50 yard freestyle finalists at the NCAA National Swimming & Diving Championships used the grab start.

The rapid acceptance and widespread adoption of the grab start technique and the success of swimmers who used the start prompted many researchers to conduct studies that compared the relative effectiveness of different starting techniques.

Winters (1968) completed a master's thesis study comparing the conventional armswing style with the grab start. Based on kinematic data obtained from cinematography Winters concluded that the grab start was significantly faster than the conventional armswing method to a distance of 10 yards. Using cinematography, Hanauer (1972) found that his subject exhibited both a lower trajectory of CM through the air and left the block sooner when using the grab start technique as opposed to the conventional style.

During the 1970's, more cinematographical studies (Roffer, 1971; Hanauer, 1972; McCutchan, 1973; Van Slooten, 1973; Bowers, 1975; Lowell, 1975; Gibson & Holt, 1976; Havriluk, 1979; Lewis, 1980;) were conducted to evaluate the effectiveness of the conventional and grab starting techniques. The majority of the researchers confirmed that swimmers using the grab start technique left the block in less time and/or reached a specified distance earlier when compared to swimmers using more conventional starting styles. Thus, the superiority of the grab starting technique was established when kinematic variables such as time off the starting block, flight time, time to a given distance, and velocity at takeoff were considered.

Analysis of the mechanics of the grab start technique provided further information on the specific factors that contributed to the grab start's superiority. The most important differentiating factors identified by Lowell (1975) were the swimmer's ability to attain a wider base of support, due to the contact of the hands with the starting block, which made the technique more stable than the conventional starts, and the ability to place the center of mass (CM) of the body further forward when using the grab start. Maglischo (1982) commented that the grab racing start, with the added use of the hands to grip the starting block, minimized the swimmer's tendency to false start. Roffer (1971) also found that the grab starting technique more readily facilitated forward motion than the conventional start because the latter technique required excessive movements and therefore increased the time spent on the starting block.

One disadvantage of the grab start has been identified. Shierman (1979) conducted a study that used a Kistler force platform to record the horizontal forces (anteroposterior and lateral) and vertical forces exerted in grab start and conventional start performances. While Shierman observed differences in force patterns and in total force application of the starts, exact force values were not obtained and the differences were largely approximations. Based upon a visual observation of the force patterns, Shierman noted that in all grab start performances the initial pull of the arms produced a downward vertical force. Guimaraes (1982) found that the forces applied by the hands in a forward and downward direction to the starting block "almost without exception...elicited a reaction that...tended to pull the swimmer downward and retard forward motion."

Despite the above identified disadvantage of the grab starting technique, coaches and researchers uniformly agreed upon several mechanical advantages of the grab starting technique over earlier styles. The purported advantages included the swimmer's ability to achieve a wider and more stable base of support while on the starting block, minimized tendency to false start, and a lower trajectory. However, the most decisive factor which resulted in the grab start replacing the conventional start as the technique of choice was the general finding that swimmers using the grab start were faster off the starting block and reached a specified distance in less time than swimmers using other starting techniques.

Introduction of the Track Style Racing Start

In 1973 Fitzgerald experimented with using a track style racing start in competitive swimming. Fitzgerald

(1973) visually determined that swimmers using the track style start entered the water in a shorter time than swimmers who used the grab and the conventional starting techniques. Fitzgerald recommended the track starting technique for all competitors, especially for sprinters.

A swimmer performing the track starting technique assumes a forward-backward stance position, with approximately 16-22 inches measured between the two feet (the distance from the toes of the front foot to the toes of the back foot). The toes of the forward foot grip the edge of the starting block. On the ready command, the hands grasp the front edge of the starting block (the hand on the side of the forward foot grabs the starting block on the outside of the foot) and the back leg is flexed so that the hips are positioned directly above the back foot. The swimmer loosely tucks the head between his/her arms while simultaneously pulling forward with the arms and straightening the front leg. In this position, the arms and legs counterbalance each other as the swimmer maintains a balanced and ready position until the starting signal is given. When the start signal is given, the head is lifted, the arms pull forward and both legs begin to push downward and backward against the starting block. The back foot leaves the starting block shortly after the CM moves forward and beyond the starting block. The forward foot is the last body part to leave the starting block.

Unlike the swimming version, the track start technique has long been familiar to track and field coaches and athletes and many studies have been conducted to analyze the running track start. One primary consideration of earlier coaches and researchers was the question of what running start stance produced the optimum starting performance.

There has been general agreement among track and field researchers (e.g., Henry, 1952; Hogberg, 1962; Menely, 1968) that the medium stance of approximately 16-22 inches (40-55 centimeters), measured from the toes of the front foot to the toes of the back foot, was the most desirable starting position. In all cases racing start performances that used the medium stance, as opposed to the elongated (longer/60-70 centimeters) or the bunch (shorter/25-30 centimeters) styles, resulted in significantly shorter times to distances of 5 and 10 meters, which were the two distances common in all of the above studies. Seidel et al. (1975) further noted that the medium stance combined the explosive, powerful advantage of the bunch start with the increased stability obtained from the elongated stance while also minimizing the corresponding disadvantages of limited stability and lack of explosive power.

Although Fitzgerald introduced the swimming track start in the early 1970's, few empirical investigations of the track technique were conducted until later in the decade. Hunt (1976) determined that the mean difference (though not statistically significant) in time to water entry was 0.066 seconds shorter for track start performances when compared to grab start trials. When the respective mean track and grab start times (2.067 and 2.133 seconds) were converted to the distance traveled in feet per second, track start performers achieved a value of 9.675 feet per second and grab start performers achieved 9.376 feet per second. Although Hunt noted that the mean difference of 3.592 inches per second was not statistically significant, one might argue that such a difference could affect the outcome of a competitive swimming event.

Maglischo (1982) provided further support for the above findings of Hunt when he demonstrated that improved starting performances could reduce racing times by up to 0.10 seconds. This is particularly significant after a close examination of the results at the 1994 NCAA Division I National Swimming and Diving Championships. Only 0.05 seconds separated first and second place and ninth through twelfth places in the women's 500 freestyle and the mens 50 freestyle respectively (Swimming World, 1994).

As a means of determining the optimum starting stance using the track start technique, LaRue (1985) mounted a running starting block onto a swimming starting block. As earlier noted, similar investigations of the track start used in running events had already demonstrated that track start performances, in which a medium stance (approximately

16-22 inches/40-55 centimeters between the feet) was adopted, resulted in significantly shorter times to distances of 5 and 10 meters when compared to performances that used the bunch stance (approximately 10-12 inches/25-30 centimeters) or the elongated stance (approximately 24-28 inches/60-70 centimeters). LaRue found that positioning of the feet in a medium stance, compared to a bunch or elongated stance, resulted in faster starting performances to a distance of 4 meters from the starting block.

Researchers who experimented with the track racing start technique also reported mechanical advantages associated with performances that used the track technique. Fitzgerald (1973) observed that the track starting technique enabled a swimmer to avoid a false start due to the wider base-of-support achieved by the forward and backward stance positioning of the feet. Another feature that greatly enhanced a swimmer's ability to prevent false starts was that a swimmer using the track technique did not have to delicately balance the CM of the body over the front edge of the starting block as occurs in grab start performances. In the track start, the CM of the body is centered above or slightly behind the base-of-support created by the forward-backward stance.

Counsilman (1988) also noted that the track technique enabled the swimmer to achieve a lower CM of the body which resulted in increased stability in the starting position when compared with the earlier starting techniques. In the American Swimming Coaches Association January, 1984 Newsletter, Counsilman noted that the track start was "the safest of all the starts and that underwater photographs of the three starts [grab, scoop and track] ... reveal [the track start] to be not only the fastest, but the shallowest of the three and, therefore, the least hazardous (p. 23)." He concluded that the track start was the safest racing start because it permitted the swimmer to make a more shallow water entry.

A second advantage associated with shallow water entries was identified by Kirner, Bock and Welch (1989) who investigated both the grab and track starting techniques using two different water entry methods, the hole and shallow entry. Kirner et al. concluded that the track style starting technique, combined with a shallow water entry, resulted in the shortest times to water entry when compared with combinations of the other three starts and water entries.

Ayalon, Van Gheluwe and Kanitz (1975) and Nelson and Pike (1977) also found that the forward-backward stance allowed the swimmer to assume a lower, more stable starting position. Ayalon et al. compared the conventional backward-forward armswing start, the grab start, the bunch start and the track start and determined that the lower starting position achieved in the bunch and track starting techniques (lower vertical positioning of the CM) contributed to the swimmer's ability to achieve greater acceleration off the starting block and shorter times to water entry. Ayalon et al. further noted that the additional contact time of the forward foot with the starting block contributed significantly to the faster takeoff and water entry times attained in track start performances.

Research Comparing Current Starting Techniques

Another consideration for racing start performance was identified by Kirner, Bock and Welch (1989), who found no significant difference between track start and grab start trials when the two starting techniques were timed to an 8.0 meter distance. The researchers attributed this fact to the glide phase of the start, and commented that swimmers should learn to maximize effectiveness during the glide phase by streamlining and kicking as soon as possible. A similar conclusion was made by Nutzel and Thoma (1986) who not only commented on the importance of a "technically flawless follow-through" during the final phase of the racing start but who also found that effective flight, entry, and glide portions of a racing start performance were more dependent upon "the swimmer's coordinative capability -- for example, motor control or feeling for the water (p. 5)" than upon force components produced while on the starting block. Hay (1986) concurred with Nutzel and Thoma's findings when he reported that, "...the most important determinant of a successful grab start...[is] what the swimmer does to minimize the resistive forces during the glide (p. 57)."

The fact that the improvement of specific motor skills (e.g., streamlining and learning to kick sooner) can result in a more effective racing start performance indicates that a starting performance can be improved considerably without giving any attention to what occurs on the starting block. It would thus appear that there are two distinct phases of a racing start performance, one, the initial force producing phase, and two, the motor control or skill phase associated with the glide. Optimizing both phases is essential for an effective racing start.

This leads to another important issue raised by Havriluk (1979), who suggested that a racing start be defined to "include only the distance over which positive acceleration exists" (p. 90). If Havriluk's definition is adopted, and the observations from other researchers (Kirner et al., 1989; Nutzel & Thoma, 1986) are given serious consideration, then it would appear logical to direct additional attention to the aspects of racing start performance that occur on the starting block. To analyze the kinetic components of a racing start performance one must focus on the force-producing phase of the racing start.

Several studies have been designed to investigate components of force associated with swimming racing starts.

One such study was conducted by Nutzel and Thoma (1986). These researchers compared performances of the conventional circular armswing technique with grab style racing starts and found the latter style to record significantly smaller times than the former style for block time and to a distance of 5.5 meters. However, the authors (1986) found no relationship between performances that resulted in the 5.5 meter distance being reached first and those that produced the greatest horizontal and vertical force values at takeoff. This last point lends further support to the idea that factors other than those which produce force greatly affect the later phases of a racing start.

The impulse-momentum relationship is another aspect of racing start performances that has been investigated by researchers. Payne & Blader (1971), referring to the running track start, stated that impulse was the most important kinetic variable to consider and that it is advantageous to produce the greatest amount of horizontal impulse possible.

Summary

The introduction of the grab start to swimming and its initial success spurred a great deal of research designed to investigate its relative effectiveness when compared to alternative starting techniques. Miller, Hay and Wilson (1984) cited thirteen studies conducted to compare and determine differences between the grab start and the other previously used starting techniques. By the mid-1970's researchers generally agreed that the grab start was significantly faster than the previously used racing starts.

The introduction of the track start in the early 1970's did not lead to the same overall acceptance and response that the grab start had received in spite of the many advantages identified with this start. Counsilman noted (1984) that Dara Torres and Rowdy Gaines, once world record holders in the 50 meter freestyle and 100 meter freestyle, respectively, both used the track start. In comparison with the research involving the grab start and earlier techniques, relatively few studies have been conducted to examine the effectiveness of the track start, the most recent starting technique to appear in competitive swimming, and to compare it with the more popular grab style.

Many studies cited (Fitzgerald,1973; Ayalon et al., 1975; Nelson and Pike, 1977; Hunt, 1976; LaRue, 1985; Hay, 1988; Kirner et al., 1989) have determined, through observation or analysis, that track start performances resulted in significantly faster times than grab start trials when the time leaving the starting block was measured, or when the distance to a specified point (water entry, 5.0 meter, etc.) was compared for the two starts. Although some of these researchers also found that track start performances resulted in the production of greater horizontal accelerations and velocities, none of these researchers conducted an investigation to compare the kinetic components of starting performances. Thus, Hay's (1986) comment that, "If anything further is to be obtained by analyzing the starting techniques used in competition, it will most likely be through the use of technologies other than cinematography (p. 55)," is especially noteworthy.

To this date there remains controversy as to which starting technique produces superior performance. Many questions still remain to be answered. Do kinetic and kinematic differences exist between the grab and track starting techniques? Can a comparison of horizontal impulse and vertical impulse provide additional understanding to the present knowledge of racing starts? Does a difference exist between the grab and track starting techniques in terms of the average force produced? Can predictions of kinematic outcomes be made from kinetic data?

The need to further investigate the relative merits of the two most prevalent starting techniques currently used in competitive swimming, using instrumentation specifically designed to measure kinetic and kinematic variables, prompted the design of the present research project.

CHAPTER III
METHODS AND PROCEDURES

Introduction

The purpose of this study was to compare the kinetic and kinematic components of grab and track racing start techniques used in competitive swimming, and to identify important differences that contribute to the effectiveness of each starting technique.

This chapter includes a description of the methods and procedures used and is divided into the following sections: subjects, apparatus, kinetic data, digitizing method, kinematic data, experimental procedures, analysis of data, and experimental design.

Subjects

Twelve female swimmers were originally selected and volunteered for this study. Subject selection was completed jointly by the researcher, the swim coach for the Corvallis Aquatic Team (a sanctioned United States Swimming age group team), the head coach of the Crescent Valley High School swimming team, and by the Oregon State University women's varsity swimming coach. Subsequent to selection two subjects withdrew from the study. The range in competitive swimming experience of the remaining ten subjects included competing at the Junior Nationals, Senior Nationals, P.A.C.

West and Pacific Ten Championships. The mean 50 & 100 yard freestyle times for the ten subjects were 26.04 seconds and 56.60 seconds respectively. Subjects ranged in age from 16-21 years (average of 19.2 years), with a range in height of 162.0-174.0 cm (mean = 168.1 cm). Body mass ranged from 54.8-76.9 kg (mean = 63.7 kg). Additional subject information is presented in Appendix A.

Apparatus

Kinetic components related to both starting techniques were measured using the following instrumentation: a Paragon starting block, a Kistler force platform and amplifier, a Microsoft Disk Operating System (MS-DOS) compatible computer, a Metrabyte analog to digital (A-D) board.

Paragon Starting Block

A Paragon Standard removable starting block was used in this study. The starting block was donated by KDI Paragon, Inc. The top of the starting block was made of a nonslip material. The length of the starting surface was 24 inches (approximately 61 centimeters), and the width measured 19.75 inches (approximately 50 centimeters). It was necessary to separate the top starting block surface from the stainless steel base so that the force platform used in this study could be mounted to the starting block (see Figure 15).

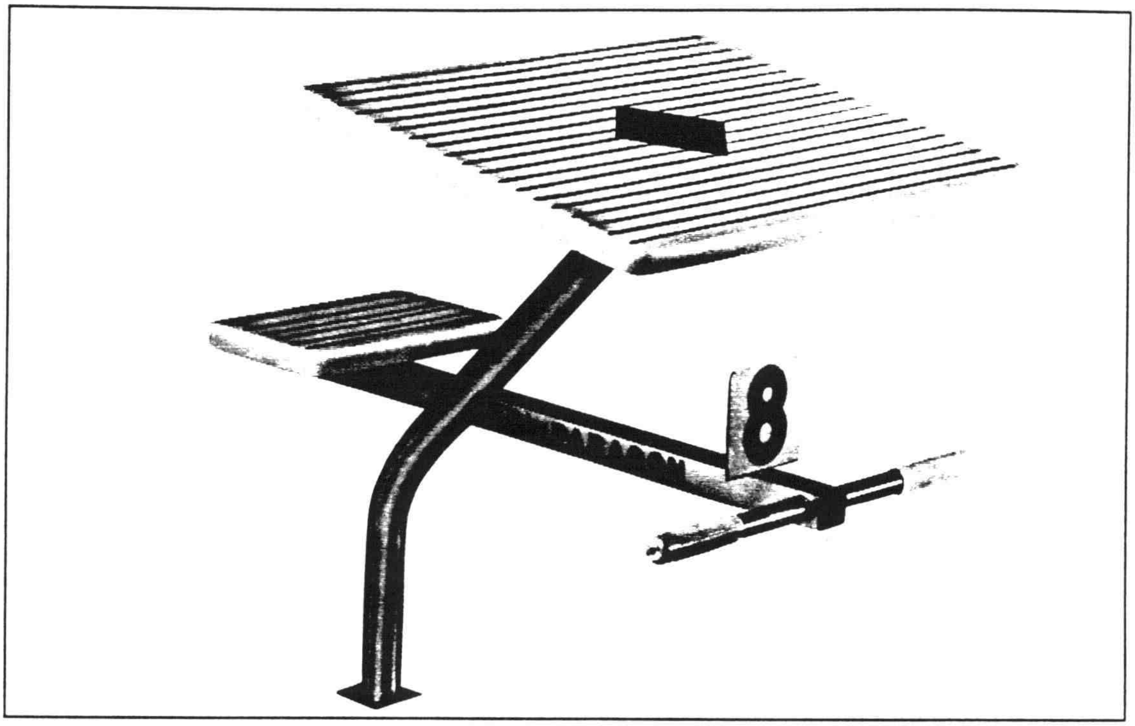

Figure 15. Paragon starting block (model #22125).

Starting Block Set-up

The entire starting block set-up, inclusive of the Kistler force platform, was as follows:

A Paragon starting block was installed at the deep end of the pool in the Langton Hall natatorium on the Oregon State University campus. Modifications, with respect to the original height of the Paragon starting block, were necessary for three major reasons. The first reason related to the unique design (circa 1926) of the swimming pool decks where the top deck edge was sixteen inches above the water surface (see Figure 16). A second factor was the NCAA rule (Rule 1, Section 2, Article 7) stipulating that "the front

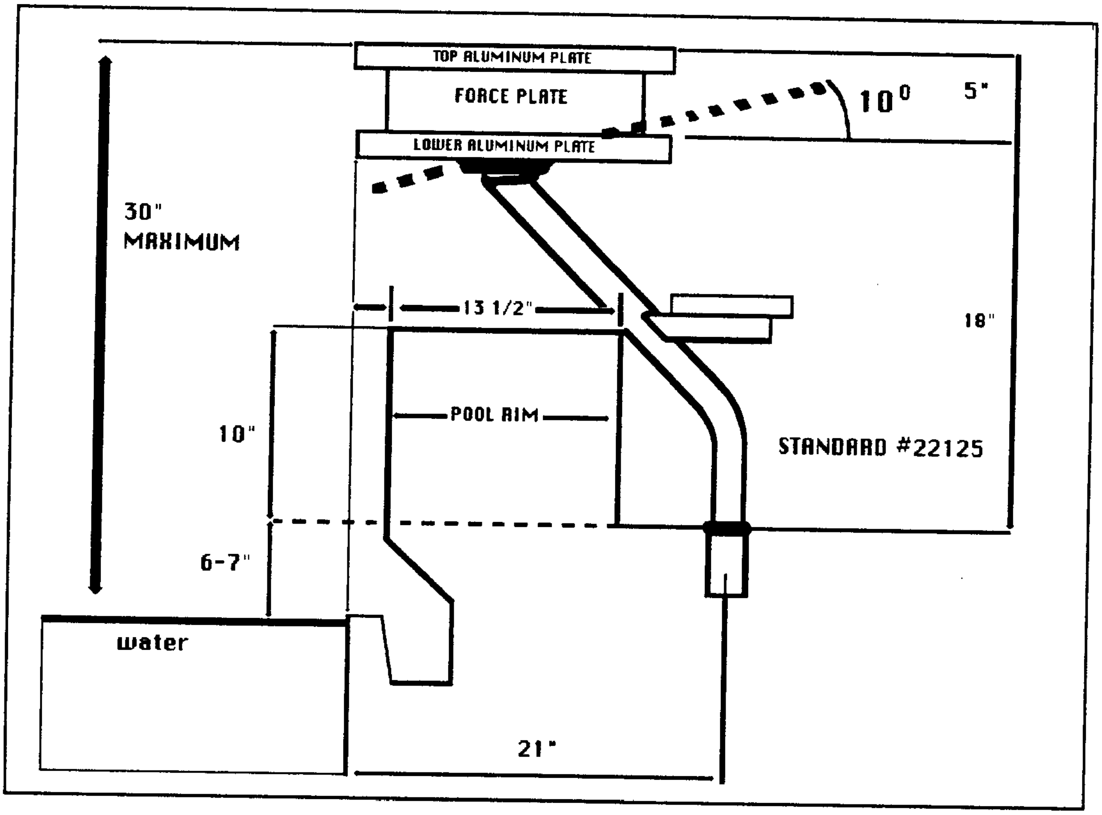

Figure 16. Cross sectional view of swimming pool and starting block with force platform.

edge of the starting block should not exceed 30 inches (76.20 centimeters) in height above the surface of the water and may not extend over the water beyond the end of the racing course" (NCAA Men's and Women's Swimming and Diving Rules, 1990). A third factor that was necessary to consider was the inclusion of the total height of the force collecting instrumentation in determining the above NCAA 30 inch requirement.

The starting block manufacturer, Paragon, completed modifications to the starting block prior to shipment to OSU so that the resulting set-up did not exceed a height of 30 inches (76.20 centimeters) above water level. It was also necessary to eliminate the starting grip used in the backstroke event as a result of the pool's top gutter width of 13.5 inches. The backstroke starting grip was removed by Paragon prior to shipment.

Two aluminum plates, plus the Kistler force platform were mounted onto the starting block. The two aluminum plates (0.625 x 20 x 24 inches/1.59 x 50.8 x 61 centimeters) had a mass of 26.3 kilograms each. The plates provided a solid contact surface for the force platform. The set-up is illustrated in Figure 17.

The lower aluminum plate was attached directly to the Paragon starting block standard using the bolts and configuration established by the manufacturer. Four additional holes, drilled to match the four bolt holes below the cover plates on the Kistler force platform, were drilled into the lower aluminum plate. Bolts of sufficient length were obtained to span the force platform and securely thread into the aluminum plate. In this manner, the force platform was securely mounted to the lower aluminum plate and to the Paragon starting block standard. Two supporting braces, reaching from the lower aluminum plate to the upper deck of the swimming pool, were added to the starting block unit to minimize vibration. The resonant frequency of the entire starting block set-up was estimated to range between 10-20 Hz, based on typical force oscillation after takeoff. The

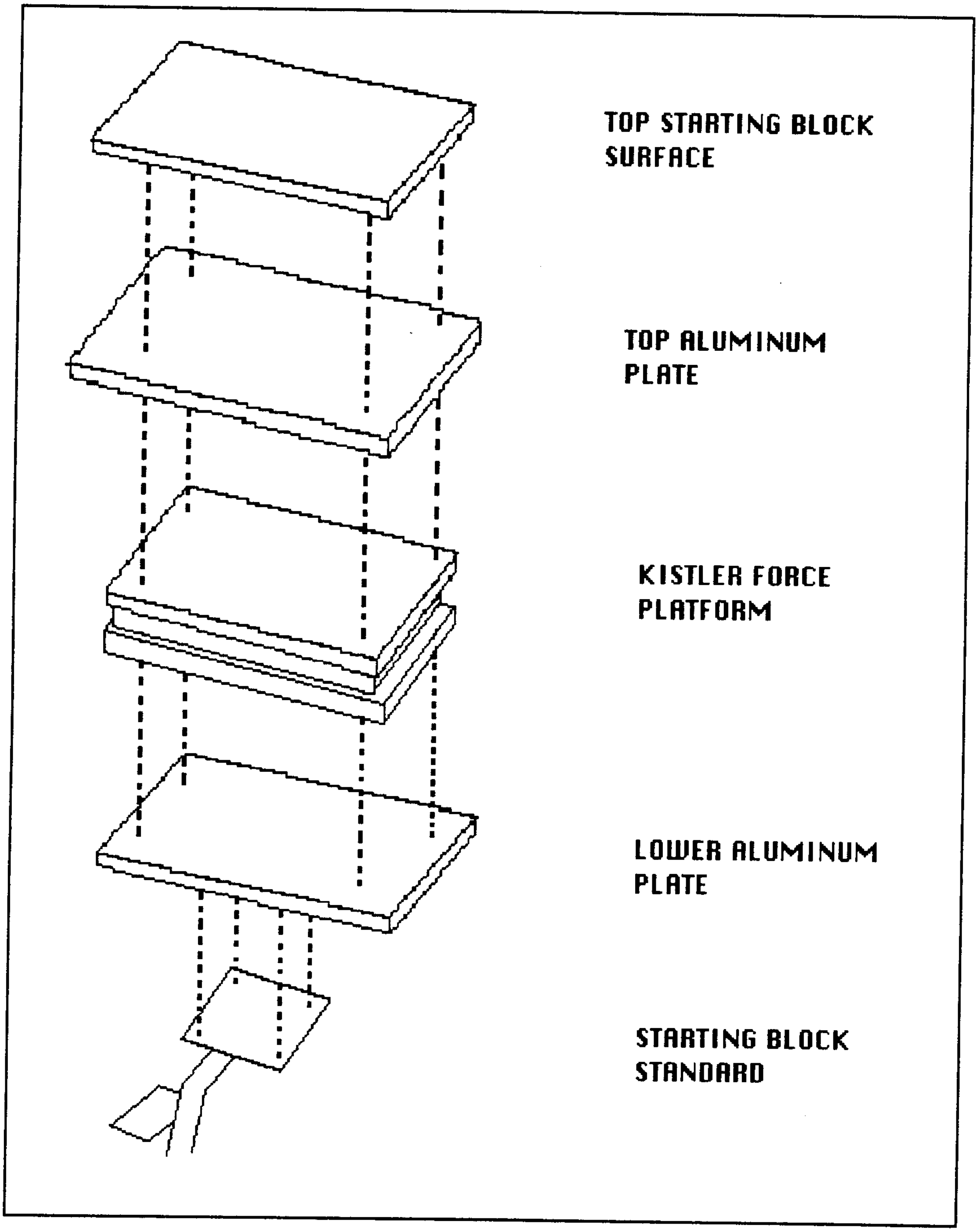

Figure 17. Starting block set-up.

second aluminum plate was drilled at each of the four corners to match the four corner bolt holes on the Kistler force platform and was attached to the force platform at these locations. The original top surface of the Paragon starting block was attached to the lower unit using bolts that were drilled into the four corners of the aluminum plate.

The socket for the starting block was permanently anchored in the floor of the pool deck according to the manufacturer's instructions (see Figure 18). A hole eight inches in diameter and ten inches deep was drilled into the tile deck. The stainless steel starting block socket was centered in the hole and aligned parallel to the pool edge. An epoxy and sand mixture was used to fill the space around the socket. A cover plate was securely attached to the socket when the starting block was not being used for data collection. When installed, the top surface of the cover plate was flush with the swimming pool deck.

Kistler Force Platform

Force data were collected for each racing start trial using a Kistler force platform, type 9281B (see Figure 19), mounted to a Paragon starting block. The force platform measures three orthogonal force components, two shear (F_x and F_y) and one vertical (F_z), the point of force application (center of pressure) and the moment about the

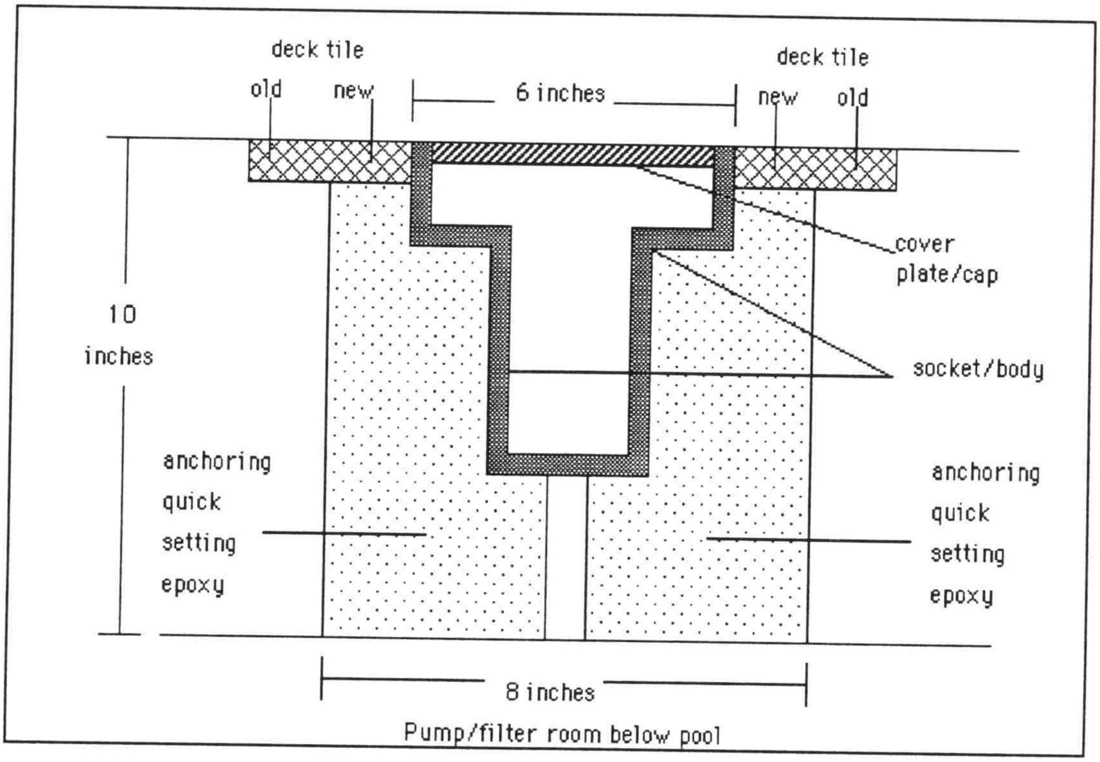

Figure 18. Anchor socket installed in floor of Langton Hall pool deck.

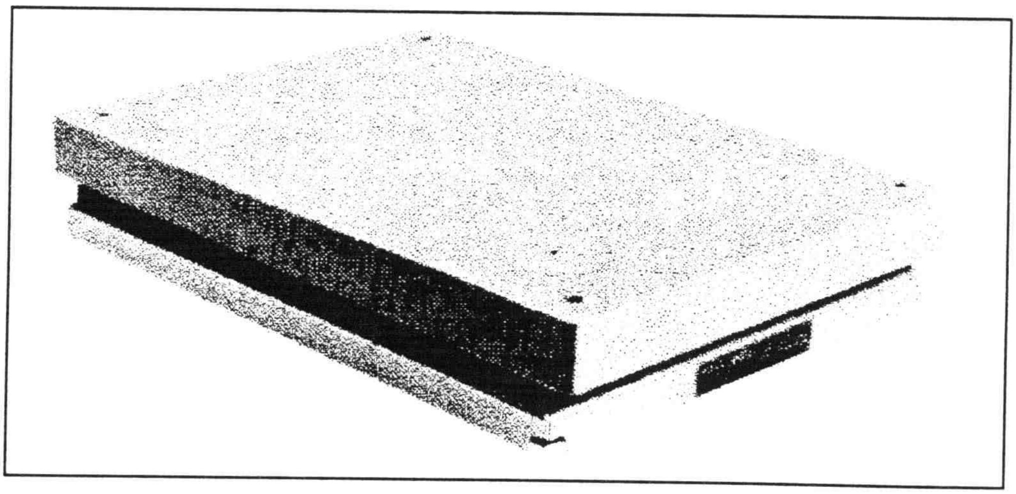

Figure 19. Kistler Force Platform (type 9281B).

vertical (F_z) axis. Only the F_y, horizontal, and F_z, vertical, force components were measured in this study. Specifications of the force platform appear in Table 1.

Table 1. Specifications for Kistler Force Platform and Amplifier.

FORCE PLATFORM:		
Ranges:	F_x, F_y,	-10...10 kN
	F_z	-10...20 kN
Threshold:		<20 mN
Natural Frequency:		≈850 Hz
Dimensions:		600 x 400 x 100 mm
Mass:		42 kg
AMPLIFIER:		
Output channels:	F_x, F_y, F_z	<= +/-25 mA
	a_x, a_y	<= +/- 5 mA
	M_z	<= +/-10 mA
Output voltages:	+/-10 V	
Typical total errors:	F_x, F_y, F_z	< +/-2 %
	a_x, a_y, M_z	< +/-3 %
Power supply:	220/110 V, +/-20% 90 VA 50 ... 60 Hz	
Dimensions:	491 x 388 x 320 mm	
Mass:	26 kg	

Kistler Amplifier

The Kistler amplifier used was type 9807 (see Figure 20). Specifications for the amplifier appear in Table 1.

Analog to Digital (A-D) Board

A MetraByte DAS-16 board for MS-DOS compatible computers was installed into an expansion slot in a ZENITH 386-Workstation computer. The output from the Kistler amplifier was connected to the A-D board with a MetraByte STA-16 screw terminal board. Three channels of force (x, y and z) plus one trigger/start channel were used to collect force data. The sampling frequency for each of the four channels measured was set at 250 Hz.

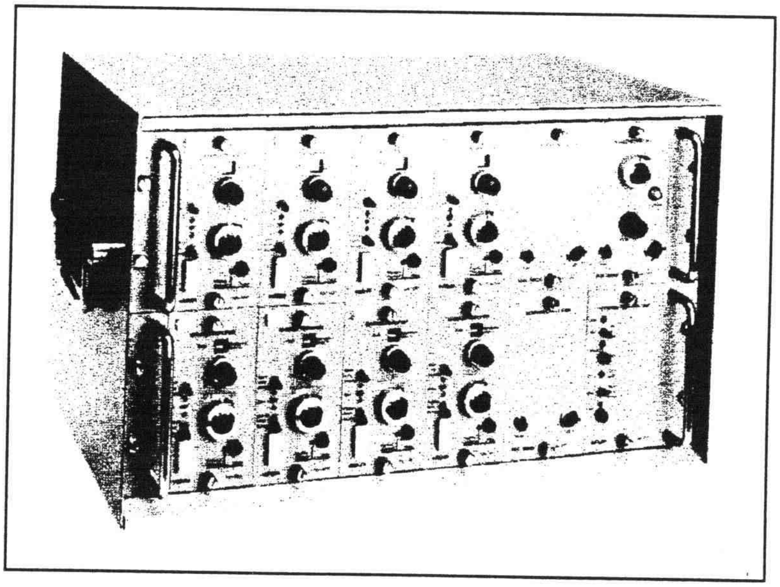

Figure 20. Kistler amplifier (type 9807).

The top surface of the starting block (and thus the force platform) was inclined at a 10 degree angle, θ (see Figure 16). True horizontal and true vertical force components (Fy' and Fz') were obtained by rotating the original force component system using following equations with θ equal to 10 degrees:

$$Fy' = Fy \cos \theta + Fz \sin \theta \qquad (3.1)$$

$$Fz' = -Fy \sin \theta + Fz \cos \theta \qquad (3.2)$$

where "Fy" and "Fz" are the forces acting on the swimmer in directions parallel and perpendicular to the surface of the force platform, respectively. Fy was taken as positive in the forward direction of the swimmer and Fz was taken positive in the upward direction. A separate analysis program was written to determine the true horizontal and true vertical force components.

Electronic Starting Signal

A Colorado Timing System Inc., Loud Speaker Starting System (model 6LS-8LS-10LS) was used in this study. The starting system microphone was used to provide the auditory starting commands to the subjects. An electronic starting signal, with a "beeper" and a flash, was used to emit the starting signal for each trial, thereby simulating a racing start situation. The electronic starting signal was preceded by a verbal command, "Swimmer take your mark". At the same instant that the starting signal sounded, a bulb, located behind the front panel of the Colorado Timing System, produced a flash of light.

The electronic starting system was interfaced with the Metrabyte A-D board to mark on the force data the exact instant that the start signal was given. This involved connecting the front panel bulb output to channel four of the A-D board. The force data were triggered by the output of the starting gun. This provided a permanent record of the start time on the F-time data.

KINETIC DATA

Kinetic data were obtained from a computer program that was written to record the motion from the time swimmer began moving until the point at which the swimmer left the starting block (takeoff). A three second sampling period with a sampling frequency of 200 Hz was used. The cutoff frequency for the Butterworth filter was 50 Hz. The impulse, or the area under the F-time curve between the beginning of motion and takeoff, was determined for each trial by numerical integration. In this manner, horizontal and vertical impulse values were obtained and subsequently, average horizontal and average vertical force values were computed. Figures 21 and 22 illustrate, respectively, the method of marking a horizontal and vertical F-time curve. Horizontal and vertical impulse (YI and ZI) values were then calculated by numerically integrating each curve.

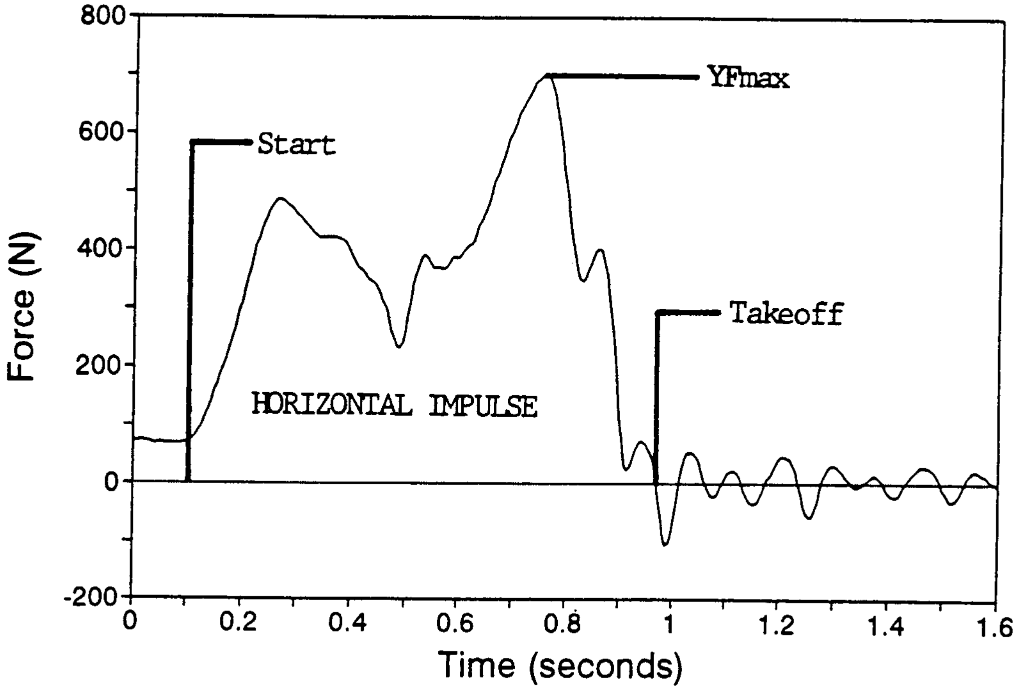

Figure 21. Area under horizontal F-time curve marked for calculating horizontal impulse (YI).

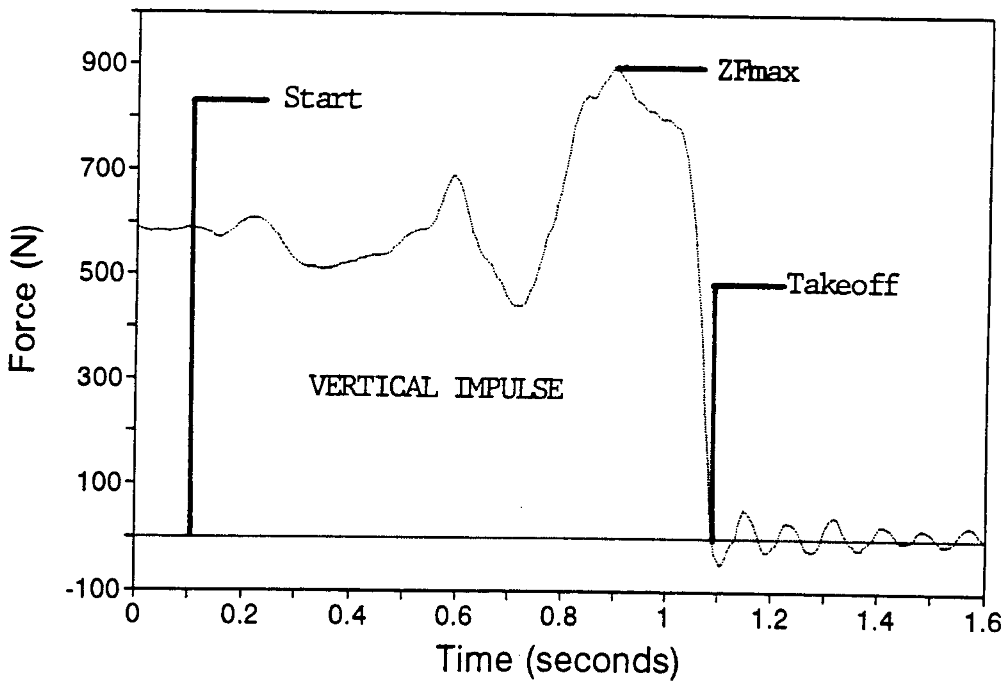

Figure 22. Area under vertical F-time curve marked for calculating vertical impulse (ZI).

Video Analysis System

The kinematic data were collected and analyzed using the following instrumentation: Panasonic AG-450 camcorder, Panasonic 7300 monitor, a ZENITH 386-workstation computer, and Peak Technologies Inc. video analysis software.

The video camera used in this study was a Panasonic AG-450, SVHS Camcorder. During video taping sessions the exposure time was set at 1/500 of a second. The camcorder was operated at a rate of 60 Hz, or 60 fields of view per second. This provided a recording rate of 30 video frames per second for analysis.

A Panasonic AG-7300, SVHS, video cassette recorder (VCR) and video monitor, BTM-1310Y, were used in the data analysis. The VCR and video monitor were interfaced with a ZENITH, 386 Workstation, MS-DOS computer and VGA monitor.

The video analysis system used in this study was a Peak 2D, Motion Measurement System, version 4.5, developed by Peak Technologies, Inc. The system provides the user with the ability to directly digitize an image that appears on the video monitor screen. Using a mouse control, an electronic cursor can be moved anywhere on the screen. By pressing the appropriate mouse button, the "x" and "y" coordinates for each specified landmark can be marked on the monitor screen and stored in the Peak system. A schematic of the force data collection and video analysis system are illustrated in Figure 23.

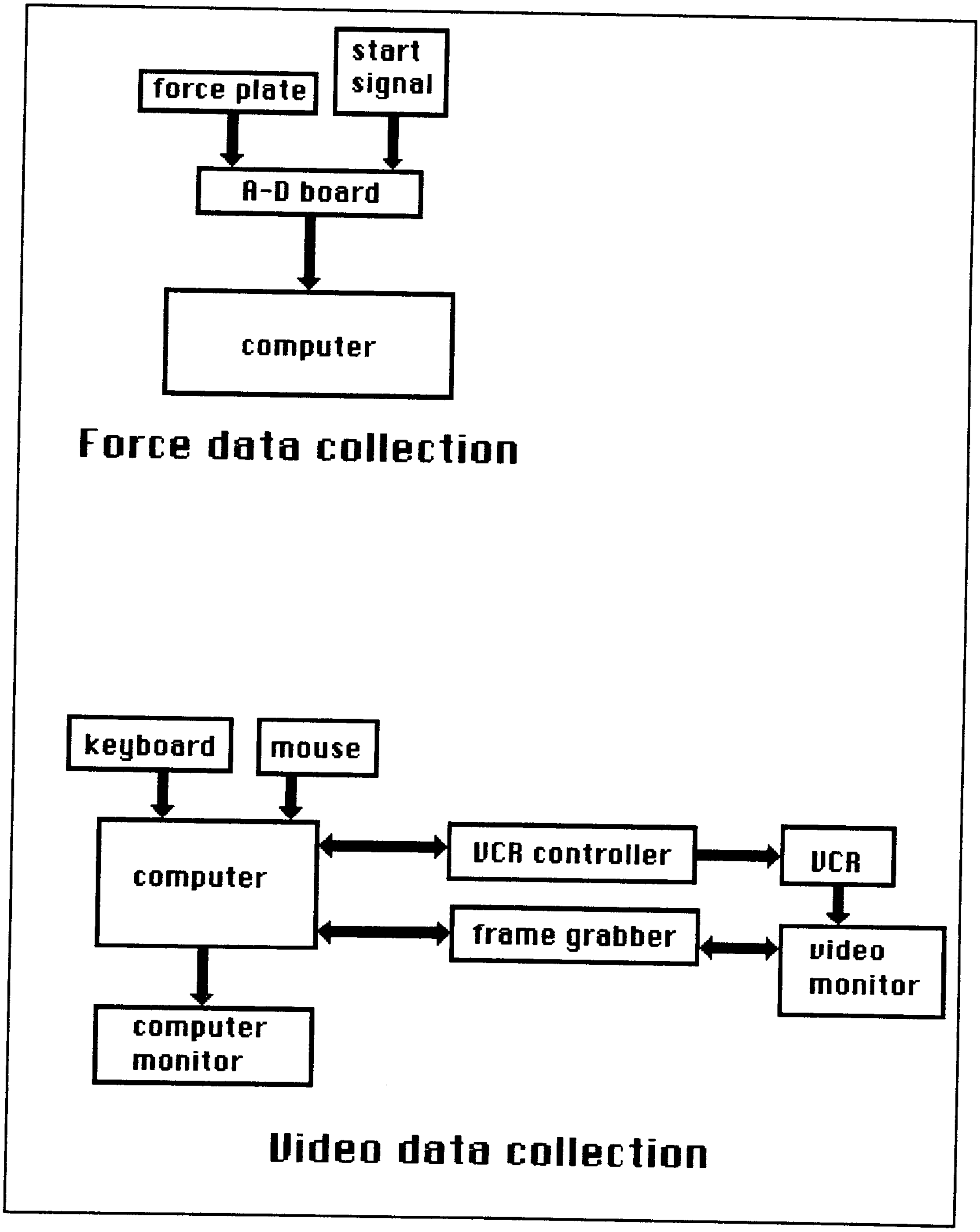

Figure 23. Force data collection and video analysis systems.

DIGITIZING METHOD

Prior to data collection, the anatomical landmarks of interest were located on each subject and marked with permanent black ink markers (see Figures 24 and 25). In the ensuing analysis, the videotape was then processed using the video analysis system. The anatomical landmarks were digitized using the Peak 2D, Motion Measurement System.

The eight body landmarks digitized in grab start performances and the eleven body landmarks digitized in track start performances are presented in Tables 2 and 3, respectively.

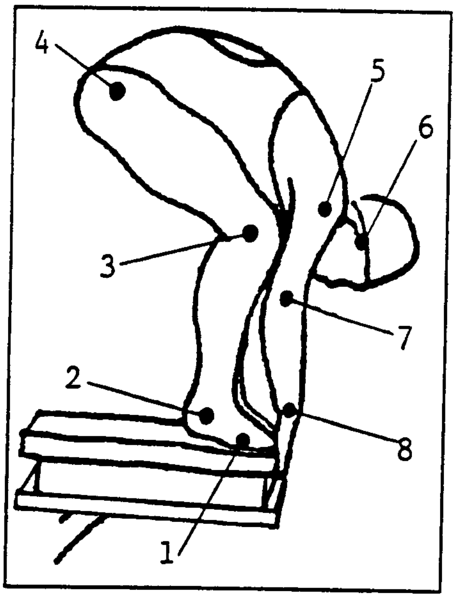

Figure 24. Eight anatomical landmarks for digitizing grab start performances.

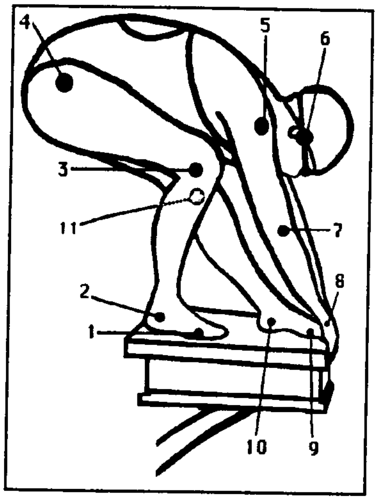

Figure 25. Eleven anatomical landmarks for digitizing track start performances.

Table 2. The eight anatomical landmarks digitized in grab start performances.

Landmark #:	**Location:**
#1	proximal end of lateral fifth-metatarsal (foot)
#2	lateral malleolus of fibula (ankle)
#3	proximal portion of lateral condyle of femur (knee)
#4	greater trochanter (hip)
#5	lateral greater tubercle of humerus (shoulder)
#6	lateral air sinus (ear)
#7	lateral epicondyle (elbow)
#8	center of lateral wrist joint (wrist)

Table 3. The eleven anatomical landmarks digitized in track start performances.

Landmark #:	Location:
#1	proximal end of lateral fifth-metatarsal (foot)
#2	lateral malleolus of fibula (ankle)
#3	proximal portion of lateral condyle of femur (knee)
#4	lateral greater trochanter (hip)
#5	lateral greater tubercle of humerus (shoulder)
#6	lateral air sinus (ear)
#7	lateral epicondyle (elbow)
#8	center of lateral wrist joint (wrist)
#9	proximal and medial end of first metatarsal farthest from camera (foot)
#10	medial malleolus of fibula farthest from camera (ankle)
#11	proximal portion of medial condyle of femur farthest from camera (knee)

KINEMATIC DATA

Linked segment models were developed for use with grab start and track start performances. The model for the grab start performances is illustrated in Figure 26 and the model for track start trials is illustrated in Figure 27.

Body segment parameters (BSP) from Dempster (1955) were used to determine the center of mass (CM) location for each

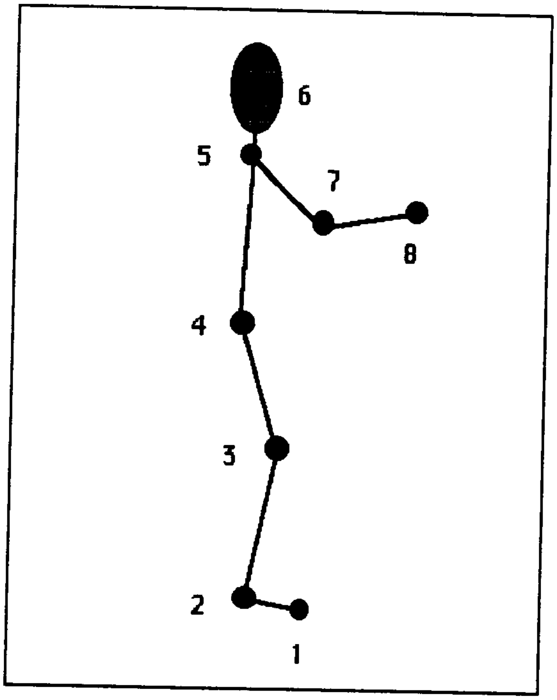

Figure 26. Link segment model for grab start performances.

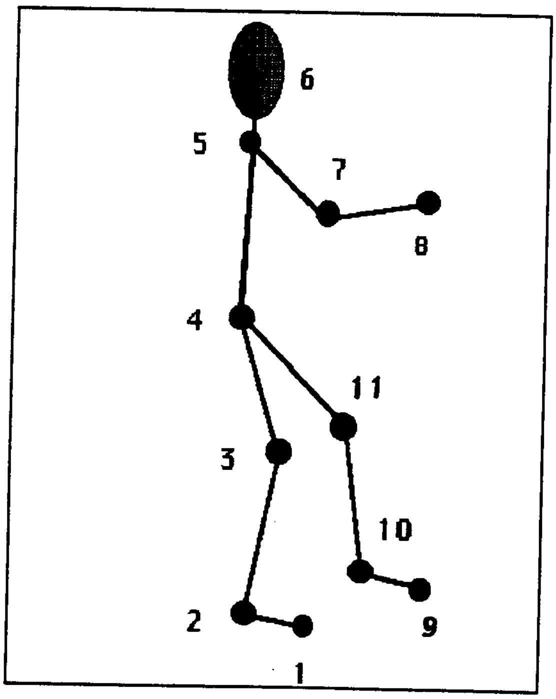

Figure 27. Link segment model for track start performances.

body segment. Dempster's data, although originally calculated from male subjects, were used in this study due to the inadequacy of BSP data from female subjects. A systematic error in calculating CM locations for the 10 female subjects was introduced by using the Dempster data based on male BSP data.

Filtering Method

In order to quantify the kinematic data it was necessary to smooth the raw data points. For this purpose a Butterworth fourth order recursive filter was used (Winter, 1990). The Butterworth fourth order filter is a double-pass routine. A cutoff frequency of 6 Hz was used.

EXPERIMENTAL PROCEDURES

The selection of the ten subjects used in this study was based upon each athlete's ability to interchangeably use the grab and the track style starts in competition. Starting proficiency was assessed and agreed upon by three coaches who had experience teaching both techniques. Three swimmers were current members of a local high school varsity team while the remaining seven swimmers were university varsity team members.

Each swimmer completed and returned an informed consent form (see Appendix B) prior to participation in this study.

An explanation of the procedures to be used was provided to the subjects, and also to their parent(s) or guardian(s), in the case of the high school swimmers. Participation in the study was voluntary and subjects were free to withdraw from the study at any time. Prior to the data collection each subject also completed a questionnaire (see Appendix C) related to their competitive swimming background and their experience using both starting techniques and the investigator recorded the subjects' height and weight.

Subjects were attired in a light colored, lycra Ocean® racing swim suit and wore latex swim caps. Anatomical landmarks were marked on the right, or field of view side, of each subject using a black permanent marker.

The data collection was completed at the Oregon State University Langton Hall swimming pool. The starting block set-up was located in lane 5, at the deep end of the pool. The video camera was positioned on the north side of the pool, beside lane 1. The distance from the camera to the starting block was approximately 8 meters. The field of view encompassed the entire starting block and the distance to water entry for all subjects (approximately 5 meters from the starting block). A dark back-drop was placed on the south side of the pool, beside lane 7, in the field of view to provide optimum contrast for the video image.

Each subject participated in one data collection session which was approximately one hour in length, at the

Langton Hall swimming pool on the Oregon State University campus. Prior to the start of data collection the subjects were given adequate time to warm up and familiarize themselves with the modified starting block and the instrumentation surrounding the starting area.

Data were collected on three trials of the grab start and on three trials of the track start. The order in which the respective starting techniques were performed was randomly assigned for each subject. Collection of force data began with the electronic starting signal and continued for 2.5 seconds. Video collection began prior to the verbal start command and continued until the swimmer had completely entered the water.

Each subject was randomly assigned an identification number (for example: S1, S2, S3, etc.) which was matched to the subject's name. Only the researcher had access to all records. All records linking subject names to subject numbers were discarded following completion of the study.

ANALYSIS OF DATA

The kinetic variables of interest were derived from the data recorded by the force platform instrumentation. These variables were: horizontal impulse, vertical impulse, average horizontal force, average vertical force, peak horizontal force and peak vertical force. In addition to the kinetic variables, block time, reaction time and movement time values were derived from the force data.

Horizontal impulse (YI) and vertical impulse (ZI) values were derived from integration of the F-t curve from the first movement after the start signal until takeoff. Evaluation of the force data resulted in the modification of vertical impulse (ZI) values and the computation of net vertical impulse (ZI) values. Differences in subject body mass existed and ranged between 52 kg to 75 kg, with a mean value of 63.7 kg (Appendix A). To account for these differences in body weight and to obtain the net impulse, body weight was subtracted from the original vertical force values. Vertical impulse (ZI) was calculated using the following equation:

$$\int_{o}^{takeoff} (VgrF - mg)\, dt \qquad (3.3)$$

with the integration calculated numerically.

Average horizontal and average vertical force values (AVYF and AVZF) were computed by dividing the impulse value by the movement time (MT) values. Block time (BT), a kinematic variable, was derived from the force data. Block time (BT) values were measured from the electronic start signal until the swimmer left the starting block.

Peak horizontal force (PYF) and peak vertical force (PZF) values, obtained from the force data, represented the force measurement with the greatest magnitude in the respective horizontal or vertical direction.

Reaction time (RT) and movement time (MT) values were also derived from the force data. Reaction time (RT) was measured as the time interval from the start signal until the swimmer first reacted by moving. Movement time (MT) data were obtained by subtracting reaction time (RT) values from the corresponding block time (BT) values.

The video data were used to derive the following kinematic variables of interest: horizontal displacement of CM from start signal to water entry, vertical displacement of CM from start signal until water entry, horizontal velocity of CM at takeoff and vertical velocity of CM at takeoff.

Horizontal displacement of CM (YDCM) and vertical displacement of CM (ZDCM) values were computed from the kinematic, or video, data as the difference in the position of the swimmer's CM from the point of takeoff until water entry. The values obtained represented the horizontal and vertical difference in position of the CM between the two points.

The horizontal velocity (YV) of the CM at takeoff and during flight is constant and can be determined from horizontal displacement-time video data. Horizontal velocity is also equal to the average horizontal velocity (AVYV). Thus, in this study, instantaneous and average horizontal velocities were computed by dividing the horizontal displacement of the CM from takeoff to water entry by the time elapsed between takeoff and water entry. The instantaneous vertical velocity at takeoff (ZV) was determined from the vertical displacement-time video data.

The resulting kinetic and kinematic data were separated into two groups of three trials for each starting technique. Each trial was assigned a trial number, for example, T1, G1, G2, T2, etc., according to the sequencing of each technique in the recorded data.

The mean value of each kinematic and kinetic variable was calculated for each set of three trials for both the grab and track techniques. The intra class coefficient was calculated in order to determine the degree of variance between each subjects' trials, for each of the two starting techniques and for each dependent variable.

A visual and qualitative comparison of the graphs depicting the force-time curve for each trial was also completed. The force data provided convincing evidence that an anticipatory factor was involved in many of the starting performances. The interpretation of these comparisons, the error involved with marking the start of movement on the F-t data and the low intra class coefficient values (see Appendix D) which were obtained for reaction time (RT) resulted in the elimination of RT as a dependent variable. In addition, and due to the method for obtaining movement time (MT) data (BT - RT = MT), movement time (MT) was also eliminated from further statistical analysis.

A correlation matrix (see Appendix E) was also computed to identify the existence of redundancy among the dependent variables. A high correlation, indicating redundancy, was found between horizontal impulse (YI) and peak horizontal force (PYF), r = 0.82, and between vertical impulse (ZI) and peak vertical force (PZF), r = 0.99. In light of these findings and the desire to minimize Type I error associated with running multiple ANOVAs, peak horizontal force (PYF) and peak vertical force (PZF) were eliminated from further analyses. Complete peak force data are presented in Appendix F, Tables F-1 and F-2.

EXPERIMENTAL DESIGN

A 2 X 10 (starting technique x subject) repeated measures Analysis of Variance (ANOVA) was conducted for each of the nine dependent variables calculated for the grab and track starting techniques. The dependent variables analyzed included the following: Horizontal Impulse (YI), Vertical Impulse (ZI), Average Horizontal Force (AVYF), Average Vertical Force (AVZF), Block Time (BT), Horizontal Displacement of CM (YDCM), Vertical Displacement of Center of Mass (ZDCM), Average Horizontal Velocity during flight (AVYV), and Vertical Velocity at takeoff (ZV). Adoption of the conservative alpha level reduced the likelihood of a Type I error as a function of conducting a total of nine ANOVAs.

CHAPTER IV
RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine if any differences were evident between grab and track racing start performances in competitive swimming that contribute to start effectiveness. Ten subjects, equally proficient in each starting style, completed three trials using each start technique. The mean values for the two sets of three trials, were analyzed using 2 x 10 (starting technique x subject) single-factor repeated measures Analyses of Variance (ANOVA) to determine if differences existed between the two starting techniques for each of nine dependent variables. A more conservative alpha level of 0.01 was chosen for this study to account for the increased Type I error associated with the conduction of multiple ANOVAs.

This chapter is divided into the following sections: Organization of Data for Analysis, Kinetic Results, Kinematic Results, Qualitative Analysis, Location of CM During Start Performance and Discussion of Results.

Organization of Data for Analysis

Thirteen dependent variables were originally selected for comparison in this study (see Chapter I). After an initial observation and evaluation of the kinetic and kinematic data, four variables were eliminated from further statistical analyses.

A visual observation of the F-time curves, obtained from the force platform data, indicated that reaction time (RT) values (see Table F-1, Appendix F) were not valid. Two factors contributed to the lack of validity. First, some error was associated with the method of marking the beginning of movement on the F-time curve. Secondly, in a majority of trials, the data obtained from the force platform showed that movement occurred adjacent to or shortly after the electronic start signal was given. These findings determined that an anticipatory factor existed and indicated that a majority of the reaction time (RT) values achieved by swimmers using both techniques were not within the accepted range for reaction time. Based upon the above two factors, the reaction time (RT) values were determined to not be valid. In addition, the results of a test for intraclass reliability for mean reaction time (RT) values revealed the following coefficients for grab and track start performances, $r = 0.091$ and $r = 0.090$, respectively. These low coefficients, indicative of high variability among subjects for each starting technique and across all trials, provided further justification for the elimination of reaction time (RT) as a dependent variable.

Movement time (MT) data were derived by subtracting RT values from the corresponding block time (BT) values (see

Table F-2, Appendix F). Given that reaction time (RT) was eliminated as a dependent variable, movement time (MT) values were also determined to be invalid and subsequently eliminated.

The correlation matrix data were used to identify the existence of redundancy among dependent variables. In addition, the matrix data identified kinetic and kinematic dependent variables that were strongly correlated.

In addition to the quantitative analyses conducted for each of the nine dependent variables, qualitative comparisons of the location of CM in performances using the two starting techniques were completed for the following variables: (1) the horizontal location of the CM in ready position, with respect to the front edge of the starting block; (2) the vertical location of the CM in ready position, with respect to the front edge of the starting block; (3) the vertical displacement of the CM from ready position to the highest point after hand release; (4) the vertical location of CM at takeoff; (5) time elapsed from point when vertical location of CM is even with front edge of starting block to water entry; (6) vertical displacement of CM from point when vertical location of CM is even with front edge of starting block to water entry. Complete data tables are presented in Appendix G (see Tables G-1 through G-6).

Kinetic Results

The results of 2 x 10 (starting technique x subject) repeated measures ANOVAs revealed significant differences in mean values between starting techniques for three of the four kinetic variables analyzed. Main effect findings for starting technique were evident for the dependent variables of vertical impulse, ZI ($F = 15.325$, $p = 0.004$), average horizontal force, AVYF ($F = 11.726$, $p = 0.008$) and, average vertical force, AVZF ($F = 20.393$, $p = 0.002$). No significant findings were obtained for horizontal impulse (YI). A summary of the statistical results for these four kinetic dependent variables is presented in Table 4.

The first kinetic hypothesis tested stated that track start performances would achieve horizontal impulse (YI) values that were significantly larger than values achieved in grab start performances. The mean horizontal impulse (YI) values obtained for performances using both techniques were not significantly different. Five subjects (S1, S3, S4, S5, S9) achieved greater mean horizontal impulse values using the track start technique when compared to the grab start. For three subjects (S6, S7, S8) the mean values associated with track and grab start performances were almost equivalent, and for the two remaining subjects (S2, S10) the horizontal impulse values obtained for track start performances were less than those associated with grab start performances (see Table 5).

Table 4. Summary of Statistical Analyses of Kinetic Data (n=10).

DEPENDENT VARIABLE:	GRAB START Mean (SD)	TRACK START Mean (SD)	F-value	p-value*
Horiz Impulse (YI), (Newton·seconds)	264.9 (42.4)	269.8 (43.9)	3.90	0.080
Vert Impulse (ZI) (Newton·seconds)	-17.8 (24.9)	-31.4 (21.7)	15.33	0.004*
Aver Horiz Force (AVYF) (Newtons)	354.2 (49.3)	391.6 (68.2)	11.73	0.008*
Aver Vert Force (AVZF) (Newtons)	-22.3 (29.92)	-43.5 (27.82)	20.40	0.002*

* significant at the 0.01 alpha level

These statistical findings did not provide support for the original hypothesis.

A review of the mean values for vertical impulse (ZI) as a function of starting style indicated that track start performances for all but one subject (S10) resulted in vertical impulse values that were less than grab start values (see Table 5). Subject five (S5) was the only subject to achieve positive vertical impulse values, however, the above pattern (smaller mean value for track start performance) was still observed. Mean values for vertical impulse (ZI) in track start performances ranged

Table 5. Means and Standard Deviations for: Horizontal Impulse (YI) and Vertical Impulse (ZI).

Subject	Horizontal Impulse (YI) (Newton·seconds)		Vertical Impulse (ZI) (Newton·seconds)	
	GRAB Mean (SD)	TRACK Mean (SD)	GRAB Mean (SD)	TRACK Mean (SD)
S1	246.8 (0.5)	257.8 (4.7)	-36.7 (6.5)	-50.1 (6.7)
S2	302.6 (8.9)	279.9 (6.4)	-28.1 (14.1)	-36.4 (13.8)
S3	317.1 (3.0)	320.8 (5.1)	-43.1 (31.4)	-65.7 (6.6)
S4	259.2 (9.9)	263.4 (6.3)	-10.5 (5.9)	-14.5 (7.7)
S5	333.7 (7.7)	347.8 (9.6)	34.2 (10.7)	12.2 (10.8)
S6	200.3 (1.6)	205.6 (2.1)	- 9.5 (3.6)	-30.5 (6.6)
S7	246.0 (2.9)	248.8 (6.2)	-12.7 (9.1)	-27.6 (2.5)
S8	215.8 (5.3)	215.0 (1.3)	- 3.7 (8.6)	-16.0 (5.3)
S9	260.6 (0.5)	278.9 (0.9)	-12.6 (7.1)	-40.3 (24.0)
S10	267.0 (5.7)	261.5 (7.5)	-55.0 (29.7)	-44.9 (19.5)

from -65.7 N·s (Newton seconds) to -14.5 N·s, with the exception of the mean value for S5 (M = 12.2 N·s). Mean values for grab start performances ranged from -55.0 N·s to -3.7 N·s, with the exception of S5 (M = 34.2 N·s). Statistical analysis ($F_{1,9}$ = 15.33, p = .004) indicated that when subjects performed the track start technique they achieved significantly smaller mean vertical impulse (ZI) values (M = -31.39 N·s, SD = 21.7 N·s) when compared to their performances using the grab start (M = -17.77 N·s, SD = 24.9 N·s). The negative values obtained for vertical impulse (ZI) indicated that the resultant vertical forces acting upon swimmers performing either starting technique resulted in movement that was slightly downward, as opposed to upward. The significantly lower vertical impulse (ZI) values obtained for track start performances when compared to grab start performances however, provided support for the second hypothesis which stated that track start performances would result in smaller vertical impulse (ZI) values when compared to those resulting from grab start performances.

The third kinetic hypothesis tested stated that larger average horizontal force (AVYF) values would be produced by swimmers using the track start when compared to the grab start technique. Mean average horizontal force values (AVYF) for track start performances for all subjects were larger than values for grab start performances (see Table 6), with the exception of subject six (S6), whose horizontal

Table 6. Means and Standard Deviations for: Average Horizontal Force (AVYF) and Average Vertical Force (AVZF).

Subject	Average Horizontal Force (AVYF) (Newtons)		Average Vertical Force (AVZF) (Newtons)	
	GRAB Mean (SD)	TRACK Mean (SD)	GRAB Mean (SD)	TRACK Mean (SD)
S1	323.7 (7.3)	404.7 (13.3)	-48.0 (7.8)	-78.6 (10.4)
S2	401.9 (11.6)	464.8 (40.7)	-36.9 (17.9)	-55.7 (16.4)
S3	369.6 (11.9)	384.9 (16.5)	-49.3 (33.7)	-79.0 (9.9)
S4	315.1 (3.7)	379.1 (16.5)	-12.7 (6.6)	-21.3 (11.8)
S5	448.1 (13.0)	527.5 (12.8)	46.3 (15.7)	19.1 (16.9)
S6	285.6 (7.2)	286.9 (16.3)	-13.5 (5.3)	-42.1 (6.2)
S7	315.4 (1.1)	347.7 (24.3)	-16.2 (11.5)	-38.5 (0.4)
S8	327.2 (8.0)	345.7 (15.1)	- 5.3 (12.5)	-26.0 (9.5)
S9	382.1 (14.8)	423.5 (6.3)	-18.7 (11.1)	-58.6 (31.5)
S10	373.0 (37.0)	351.0 (8.6)	-68.5 (38.0)	-54.7 (22.5)

force values for the track and grab start techniques were almost equivalent (285.6 N and 286.9 N, respectively). Mean values for all subjects ranged from 347.7 N to 527.5 N for the track start technique, and from 315.1 N to 448.1 N for the grab start.

The correlation matrix indicated a strong relationship (r = 0.823) between horizontal impulse (YI) and average horizontal force (AVYF). Based upon the significantly different mean values determined for track start and grab starting techniques for the comparison of block time (BT) values, the lack of significant difference in the comparison of mean horizontal impulse (YI) values, and also in light of the F-t (Force-time) relationship, significant differences were expected for the comparison of mean average horizontal force (AVYF) values between the two starting techniques. Significant main effect findings ($F_{1,9}$ = 11.73, p = .008) were found in the comparison of mean average horizontal force (AVYF) values between the two starting techniques. The results of statistical analysis provided support for the original hypothesis that swimmers using the track start would achieve significantly higher mean average horizontal force (AVYF) values (M = 391.6 N, SD = 68.2 N) when compared to the values they achieved when using the grab start technique (M = 354.2 N, SD = 49.3 N).

In contrast to the findings for mean average horizontal force (AVYF), the mean average vertical force (AVZF) values exerted when nine of the ten swimmers tested used the grab start were larger than values recorded for the same subjects using the track start. Subject five (S5) was the only subject to achieve positive values for average vertical force (AVZF) for performances using both starting techniques. These findings for S5 were consistent with the positive values S5 also attained for the variable of vertical impulse (ZI). Mean values for grab start performances ranged from -68.5 N to -5.3 N, with the exception of subject five (S5, $\underline{M}$ = 46.3 N). Mean average vertical force (AVZF) values obtained for track start performances ranged from -79.0 N to -21.3 N (S5, $\underline{M}$ = 19.1).

Information from the correlation matrix indicated a strong relationship to exist between vertical impulse (ZI) and average vertical force (AVZF), r = 0.988. Statistical analysis revealed that the mean average vertical force (AVZF) values were significantly higher when subjects performed the grab start ($\underline{M}$ = -22.28 N, $\underline{SD}$ = 29.92 N) as opposed to the track style start technique ($\underline{M}$ = -43.54, $\underline{SD}$ = 27.82 N). The direction of these differences were consistent with the findings for the comparison of mean vertical impulse values and with the fourth kinetic hypothesis tested that stated swimmers performing the grab start would achieve higher average vertical force (AVZF) values than when performing the track start.

Kinematic Results

Significant differences in mean values between the two starting techniques for two of the five kinematic dependent variables were evident from the results of five 2 x 10 (starting technique x subject) repeated measures ANOVAs conducted. A summary of the means and standard deviations for the five kinematic variables is presented in Table 7. A complete description of kinematic data for each subject is presented in Tables 8 and 9.

Main effect findings for the factor of starting technique were evident for the dependent variables of block time, BT ($F_{1,9}$ = 18.92 and p = .002), and vertical velocity at takeoff, ZV ($F_{1,9}$ = 12.39 and p = .007). No significant main effect findings were evident for the remaining three kinematic dependent variables: horizontal displacement of CM (YDCM), vertical displacement of CM (ZDCM), and average horizontal velocity during flight (AVYV).

The first hypothesis tested related to the kinematic variables stated that the contact time on the starting block (BT) following the start signal would be significantly less using the track start when compared to the grab start. The resulting statistical analysis indicated a significant main effect for starting technique. There was a significant difference between mean block time (BT) values achieved in track start performances (M = 0.769s, SD = 0.057s) when compared to the mean values for grab start performances (M =

Table 7. Summary of Statistical Analyses of Kinematic Data (n=10).

DEPENDENT VARIABLE:	GRAB START Mean (SD)	TRACK START Mean (SD)	F-value	p-value*
Block Time (BT) (seconds)	0.833 (0.056)	0.769 (0.057)	18.92	0.002*
Horiz Displ of CM (YDCM) (meters)	2.77 (0.17)	2.90 (0.23)	9.11	0.015
Vert Displ of CM (ZDCM) (meters)	1.57 (0.06)	1.60 (0.08)	4.22	0.070
Aver Horiz Velocity (AVYV) (meters/second)	4.01 (0.17)	4.07 (0.22)	1.10	0.322
Vertical Velocity (ZV) (meters/second)	0.04 (0.27)	-0.27 (0.29)	12.39	0.007*

* significant at the 0.01 alpha level

0.833s, SD = 0.056s). Mean block time (BT) values for track start performances for all but one subject, S10, were less than values for grab start performances, and ranged from 0.708s to 0.896s. Mean block time (BT) values for grab start performances ranged from 0.757s to 0.986s. The mean block time (BT) values for S10 for both techniques were 0.812s. These findings provided support for the original hypothesis that the contact time on the starting block (BT)

Table 8. Means and Standard Deviations for Block Time (BT), Horizontal Displacement of CM (YDCM), and Vertical Displacement of CM (ZDCM).

Subj	Block Time (BT) (seconds)		Horiz Displ of CM (YDCM) (meters)		Vert Displ of CM (ZDCM) (meters)	
	GRAB Mean (SD)	TRACK Mean (SD)	GRAB Mean (SD)	TRACK Mean (SD)	GRAB Mean (SD)	TRACK Mean (SD)
S1	0.837 (0.002)	0.740 (0.022)	2.63 (0.11)	2.74 (0.03)	1.56 (0.08)	1.55 (0.02)
S2	0.843 (0.047)	0.708 (0.09)	2.66 (0.09)	2.64 (0.07)	1.51 (0.04)	1.50 (0.08)
S3	0.935 (0.064)	0.896 (0.025)	2.52 (0.05)	2.83 (0.07)	1.51 (0.05)	1.57 (0.03)
S4	0.986 (0.064)	0.787 (0.047)	2.78 (0.04)	2.91 (0.04)	1.55 (0.03)	1.59 (0.06)
S5	0.784 (0.025)	0.735 (0.008)	3.11 (0.03)	3.27 (0.01)	1.71 (0.08)	1.78 (0.04)
S6	0.815 (0.006)	0.800 (0.008)	2.67 (0.01)	2.72 (0.01)	1.61 (0.01)	1.55 (0.02)
S7	0.873 (0.023)	0.757 (0.073)	2.82 (0.05)	3.04 (0.06)	1.58 (0.05)	1.61 (0.04)
S8	0.775 (0.009)	0.721 (0.039)	2.76 (0.06)	2.63 (0.05)	1.56 (0.05)	1.61 (0.06)
S9	0.757 (0.068)	0.729 (0.012)	2.96 (0.08)	3.23 (0.02)	1.50 (0.07)	1.53 (0.02)
S10	0.812 (0.029)	0.812 (0.042)	2.79 (0.02)	2.96 (0.07)	1.57 (0.04)	1.67 (0.04)

Table 9. Means and Standard Deviations for Average Horizontal Velocity (AVYV) and Vertical Velocity (ZV).

Subj	Aver Horiz Vel (AVYV) (meters/sec)		Vert Vel (ZV) (meters/sec)	
	GRAB Mean (SD)	TRACK Mean (SD)	GRAB Mean (SD)	TRACK Mean (SD)
S1	3.95 (0.07)	4.03 (0.10)	-0.06 (0.18)	-0.39 (0.18)
S2	3.99 (0.05)	4.08 (0.05)	0.11 (0.04)	-0.35 (0.19)
S3	3.79 (0.06)	3.96 (0.04)	-0.45 (0.31)	-0.63 (0.13)
S4	3.87 (0.07)	3.96 (0.06)	0.30 (0.13)	-0.23 (0.22)
S5	4.08 (0.02)	4.20 (0.03)	0.57 (0.21)	0.42 (0.08)
S6	3.80 (0.07)	3.93 (0.04)	-0.03 (0.06)	-0.37 (0.12)
S7	4.21 (0.18)	4.28 (0.05)	-0.06 (0.07)	-0.43 (0.29)
S8	4.02 (0.10)	3.85 (0.03)	0.03 (0.36)	-0.19 (0.14)
S9	4.30 (0.09)	4.54 (0.02)	-0.13 (0.28)	-0.42 (0.20)
S10	4.12 (0.05)	3.83 (0.26)	0.15 (0.05)	-0.02 (0.20)

following the start signal would be significantly less using the track style start when compared to the grab style start.

The second kinematic hypothesis tested stated that subjects using the track start technique would achieve higher values for horizontal displacement of CM (YDCM) from start position to water entry than values achieved when using the grab start technique. A statistical difference approaching significance ($p = 0.015$) was found when the mean values for horizontal displacement of the CM (YDCM) were compared between performances of the two starting techniques (see Table 8). Although mean horizontal displacement (YDCM) values achieved for track start performances were greater than grab start values for eight subjects tested (ie. S1, S3, S4, S5, S6, S7, S9, and S10), mean values were less for the remaining two subjects (ie. S2 and S8). Mean values for track start performances ranged from 2.63 m to 3.27 m. In the case of grab start performances, mean values for horizontal displacement of CM (YDCM) ranged from 2.52 m to 3.11 m. On the basis of the non-significant statistical findings, the original hypothesis was not supported.

No support was provided for the third kinematic hypothesis proposed that vertical displacement of CM (ZDCM) from start position to water entry would be significantly less for track start performances when compared to grab start performances. Mean vertical displacement of CM (ZDCM) values for all but two subjects (S6 and S10) were approximately equal irrespective of the starting technique used. The mean vertical displacement of CM (ZDCM) value obtained for track start performances was 1.596 m (SD = 0.08 m) while the mean value achieved for grab start performances was 1.566 m (SD = 0.06 m). The mean values ranged from 1.50 m to 1.78 m for the track start, and from 1.50 m to 1.71 m, for the grab start technique (see Table 8). The results of a 2 x 10 (starting technique x subjects) repeated measures ANOVA indicated no significant difference between subjects as a function of the starting technique used. These findings were not significantly different.

The next kinematic hypothesis proposed stated that the horizontal velocity of CM at takeoff, which is equal to the average horizontal velocity (AVYV) from takeoff to water entry, would be significantly greater using the track style start when compared to the grab style start. The statistical analysis that compared the mean values for track start trials (M = 4.07 m/s, SD = 0.22) with values achieved for grab start performances (M = 4.01 m/s, SD = 0.17 m/s) revealed no significant statistical difference between the two starting techniques. A review of the data presented in Table 9 indicates high variability between subjects and may, in part, account for the non-significant findings obtained. The hypothesis that mean average horizontal velocity (AVYV) values would be significantly different as a function of the starting technique used was therefore not supported.

The fifth kinematic and final hypothesis tested, stated that the vertical velocity of CM at takeoff (ZV) would be significantly less in performances using the track style start when compared to the grab style start. The results of the repeated measures analysis of variance indicated a significant difference ($p = .007$) to exist when the mean values for vertical velocity at takeoff (ZV) were compared between the two starting techniques. Subjects using the track start demonstrated significantly smaller mean values for vertical velocity at takeoff (M = -0.27 m/s, SD = 0.2 m/s) when compared to the values obtained when the grab start technique was used (M = 0.04 m/s, SD = 0.27 m/s). In addition, a review of the data (Table 9) indicated that mean vertical velocity (ZV) values for track start performances for all ten subjects were significantly less than the mean values obtained for grab start performances which further suggested a significant difference to exist between the two starting techniques.

Qualitative Analysis

The subjects' answers to the questionnaire also provided important information for the evaluation of starting performance and for the interpretation of the kinematic results in this investigation. Subject information appears in Tables A-1 and A-2 (Appendix A).

Hay (1986) writes that one of the most commonly asked sports questions is, "Which of these two techniques is better?" (p. 55). In his discussion of the various investigations conducted to address this question, Hay states that "such studies almost invariably show that the most-practised and/or the least-complicated technique yields the best result...it is only when a new technique yields a better result, despite being more complex and less practised than the old one, that any useful conclusion can be drawn from a study...and, of course, there is only a remote possibility of this occurring" (p. 56).

In the present investigation, eight of the ten subjects indicated the track start to be their preferred starting technique (see Appendix A, Table A-1). However, only one subject, who indicated a preference for the track start, had used that starting technique for more years than the grab start (5 and 2 years, respectively). The mean value across all ten subjects for the number of years using the track start was 3.8 and for the grab start was 7.1.

In light of the above subject preference for the track start, the number of years each subject had used the track start, and Hay's earlier comments, the results of this study may be especially significant considering the limited experience that the subjects had using the track start when compared to the grab start.

In addition to the above considerations, is the strong possibility that the track starting technique may be the more complex of the two styles. Researchers and coaches agree that the grab start technique is a relatively simple technique (Roffer, 1971; Bowers, 1973; Lowell, 1975). Costill et al. (1992) explain that swimmers using the grab start, upon hearing the starting signal, need only start "the body moving forward: then gravity takes over (p. 112)." Comparing the grab and the track starts, Maglischo (1993) indicated that the major difference between the two techniques exists during the preparatory phase (while on the starting block). To achieve the track start ready position a swimmer must: place the feet in a forward-backward stance position; establish counter-balance by pressing against the starting block with the forward foot; place the weight over the rear foot; keep the head down. Upon hearing the start signal, the swimmer needs to perform the following, sequential steps: begin pulling with hands and driving downward with legs; release the hands when the hips pass the front edge of the starting block; extend arms forward; and, to adjust for their lower starting position, strive to achieve the steepest possible upward angle at takeoff. Based upon the block time (BT) results of this study, all of the above steps should occur within 0.7 to 0.8 seconds.

Earlier in his same text Maglischo commented on the fact that very limited time is spent improving starting techniques, in part due to the crowded conditions and limited pool time available, and also due to the fact that the main focus of time spent in the pool is on swim training.

The preceding information suggests that the track start has greater complexity when compared to the grab start. The preference of the track start by a majority of the subjects, their limited experience using the track start compared to the grab start, and the unlikelihood of the more complex track start technique gaining popularity were considered as a result of the findings that emerged from this investigation. The following data comparing the CM location for both techniques, presented important information related to evaluating the effectiveness of a starting performance.

Location of CM During Start Performance

In an attempt to better understand the kinematic differences produced by the two starting techniques qualitative evaluation was made of critical locations of the CM during starting performances for both techniques. Evaluation was made of the following: (1) horizontal location of CM while in the ready position; (2) vertical location of the CM while in the ready position; (3) vertical displacement of CM from ready position to the highest location after hand release; (4) vertical location of CM at takeoff; (5) time elapsed and, (6) vertical displacement of

CM from the point when vertical location of CM is even with front edge of starting block to water entry. Complete data are presented in Tables G-1 through G-6 (Appendix G).

The horizontal and vertical location of the CM in ready position is an important factor to consider in a comparison of starting techniques. Researchers agree that one advantage of the track style start over other swimming starts is the swimmer's ability to achieve a lower and more stable position while in the ready position (Counsilman et al., 1988; Costill et al. 1992; Maglischo, 1993). This advantage lies in the vertical location of the CM *above* the front edge of the starting block and the horizontal location of the CM which is *behind* the front edge of the starting block.

Figure 28 illustrates the different locations of CM while in the ready position for the grab and track start techniques for the same subject. Review of the CM location data in Table G-1 (Appendix G), comparing the horizontal location of the CM between the two techniques while in the ready position, indicated that nine of the ten subjects achieved values for the track start that were greater than those achieved for the grab start. The CM location was measured with respect to the front edge of the starting block. This suggested that the CM in the ready position in track start performances is located further back from the

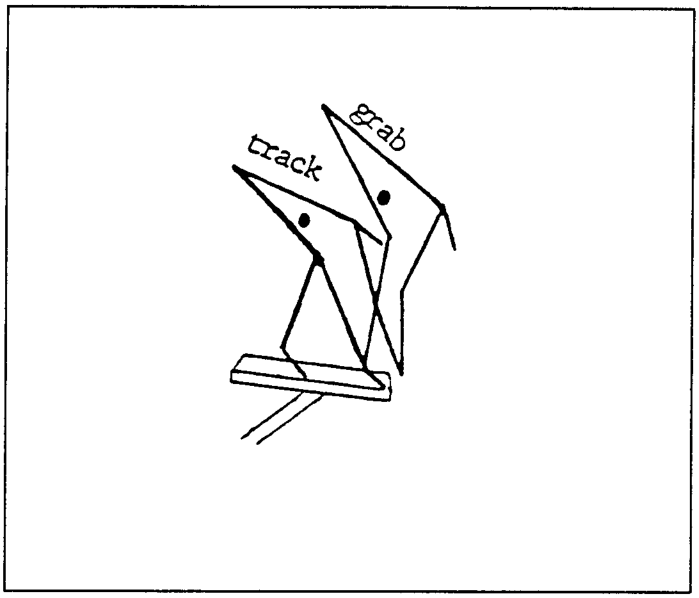

Figure 28. Location of CM in ready position for track and grab starting techniques for same subject.

front edge of the starting block when compared to the grab start ready position.

Evaluation of the CM location data, comparing the vertical location of the CM between the two techniques while in the ready position, indicated that half of the subjects (i.e., S2, S3, S5, S7, S9) achieved values for the vertical location of CM while in the track start ready position that were less than values achieved while in the grab start ready position. The values achieved for the remaining five subjects were almost equal between the two techniques. The evaluation of the vertical location of CM while in the ready position, suggested that swimmers performing the track start adopted a vertical location of CM in the ready position that was almost equivalent, or possibly slightly lower, when compared to their grab start performances.

A third table of CM location data presents the vertical displacement of the CM data from ready position to the highest point after hand release (Table G-3, Appendix G). Several researchers (Costill et al., 1992; Maglischo, 1993) have indicated that the trajectory of the CM during track start performances is more flat (less vertical and more horizontal) when compared with grab start performances. However, this point may be disputed.

A review of the location of CM data, comparing the difference between the vertical location of CM in the ready position and the location of the CM at the highest point after hand release, indicated that subjects using the track start achieved a positive value (see Appendix G, Table G-4) for all but one trial (29 of 30). In other words, the location of the CM during track start performances moved upward, and more vertically from the start signal until the highest point after hand release.

In contrast, the values achieved by subjects for half of the grab start trials completed were negative, indicating a definite downward path of the CM after the start signal. For the remaining fifteen grab start trials, values for 12 trials were noticeably less than track start values and, for the three remaining trials, the values were almost equivalent.

The decision to compute the difference in the location of CM from ready position to the highest point after hand release was based on the conclusions of Costill et al. who suggest, and Maglischo, (1993) who clearly states that, "swimmers must begin looking down at the instant their feet leave the starting [block]" in order "to establish a downward trajectory for their upper body during flight (p. 554)." Lowering the head, or looking down, causes a change in the vertical motion of the swimmer's body and, depending upon the swimmer's experience, this downward motion must be initiated at, or prior to takeoff. Performing a racing start in this manner enables the swimmer to execute a pike dive with its characteristic "hole" entry. The hole entry allows the entire body to enter the water at approximately the same point which minimizes resistance and decreases entry time. Maglischo also states that it is extremely difficult for swimmers using the track start to achieve an arced path of the CM after takeoff that is evident in a grab start pike dive. He writes that "swimmers who use the track start should try for the steepest [upward] angle of takeoff that is compatible with their low position at the start (p. 556)".

Evaluation of the vertical displacement of the CM from ready position to the highest point after hand release further suggests that swimmers using the track start, due to their ability to uniformly achieve positive displacement values, may also be able to achieve a more optimal angle of takeoff, enabling the swimmers to perform an ideal hole entry. Unfortunately, an analysis of this later aspect of starting performance, was beyond the scope of this present investigation.

Qualitative data comparing the vertical location of the CM at takeoff between grab and track start performances is presented in Table G-4 (Appendix G). These data demonstrate that the vertical location of CM at takeoff, used as the takeoff value for computation of vertical displacement of CM (ZDCM), is almost equivalent for the two techniques. Thus the values for the vertical location of the CM at takeoff do not reflect the actual difference in the vertical location of CM. Indication of the vertical change in CM that occurs after the start signal and prior to takeoff is presented in the previous location of CM data (see Table G-3).

A fifth table of CM location data lists the values achieved for the time elapsed from the point when the location of the CM was even with the front edge of the starting block until water entry (see Table G-5, Appendix G). This data indicates that each of the ten subjects performing the track start achieved lower values when compared to the values obtained when performing the grab start. These findings further indicate that swimmers reached the water in less time using the track start when compared to the grab start technique.

A final review of the location of CM data for the values related to the vertical displacement of the CM from the point where the CM was even with the front edge of the starting block to water entry also demonstrated equivalent vertical displacement values irrespective of which starting technique was used (see Table G-6, Appendix G). This finding, when considered in conjunction with the time elapsed between the same two points, indicates that swimmers using the track starting technique were able to achieve similar vertical displacements in less time, or had greater downward speed, when compared with their performances using the grab starting technique.

Discussion of Results

Agreement exists among researchers and coaches that the ideal racing start enables the swimmer to leave the starting block in the least amount of time (Roffer, 1971; Hanauer, 1972; Jorgensen, 1972; Ayalon et al., 1975; Kirner et al., 1989; etc.). Several researchers have found that swimmers using the track start leave the starting block faster and reach the water sooner when compared with swimmers using other starting techniques (Fitzgerald, 1973; Kirner et al., 1989; Costill et al., 1992; Maglischo, 1993). Cousilman et al. (1988), in a comparison of three different starting techniques using different takeoff and entry angles, determined that the track start and the flat start were superior, compared to the grab start, when timed to distances of 5 and 10 yards (p. 90). Performances of Olympic, World Record Setting, and NCAA Championship swimmers (Gaines and Torres, 1984; Eddington, 1986), who used the track start technique, demonstrated their ability to leave the starting block in less time than competitors who used the grab start technique.

Another important and related consideration is the relevance that starting performance has to the final outcome of a competitive race. It has been determined that improved starting performances can reduce racing times by at least 0.10 second (Maglischo, 1984). Winter (1990) comments on the fact that today's athletes are striving to make even slight improvements to their technique that will result in substantial and improved outcomes in competition (p. 3). Thus choosing a more effective starting technique can significantly affect the final outcome of a race, especially considering Maglischo's (1993) findings that starting times constitute "approximately twenty-five percent of a 25 (yard/meter) event, 10 percent of a 50 event and 5 percent of a 100 event" (p. 544). Several researchers (Kreighbaum and Barthels, 1985; Lewis, 1980; Yoshida and Saito, 1981; Counsilman et al., 1988) have further considered the psychological effect and/or the physical advantage gained by an athlete who leaves the starting block first, and have found that these factors also contribute to the final outcome of a race. Therefore, when selecting a racing start that is more effective, coaches and athletes must take into consideration a technique that enables the swimmer to achieve a faster starting time, and, ideally, to enter the water first.

Furthermore, it is commonly accepted that a more effective starting performance is one that not only allows the swimmer to leave the starting block in less time but also enables the swimmer to produce the greatest amount of force. Support for the above premise has been provided in earlier research (Henry, 1952; Hogberg, 1962; Menely, 1968), which analyzed the relative effectiveness of certain track starts used in running. The researchers found that it is important for the performer to optimize the force production phase of the start (while positioned in the starting block), even if slightly more time is spent in the starting block. The question remains, however, can athletes using starting techniques that generate higher force levels also leave the starting block in less time? Results of this study provide further information related to the force producing phase of racing starts and attempt to answer the above question.

A comparison of block time (BT) values between the two techniques investigated in the present study provide support for the findings of previous researchers, the observations of coaches, and the performances of top-ranked swimmers. Significant differences between the mean values for block time (BT) were evident between the grab start and track start, with the use of the track starting technique leading to significantly lower block times (BT) when compared to the times achieved when performing the grab start.

Another characteristic of a more effective starting technique is that it enables a swimmer to generate greater horizontal force, when compared with other starting techniques. Nelson and Pike (1977), in an article that reviewed research in swimming, stated that proposed use of a track start was being considered in order "to obtain an even greater horizontal impulse [than achieved by swimmers using earlier style starts] during the force production phase of the racing start" (p. 350). The authors concluded, that when using the track start the ability to achieve a lower starting position "is beneficial in the production of a strong horizontal force at take-off" (p. 348).

The findings of this study, demonstrated that swimmers using the track starting technique achieved average horizontal force (AVYF) values that were significantly greater than the values achieved when the same swimmers used the grab start. Furthermore, the results also indicated that swimmers using the track start not only achieved higher mean values for average horizontal force (AVYF), but also left the starting block in less time (BT) when compared with their performances using the grab start. It can be concluded that the track start technique was the more effective starting technique when compared with the grab style start for the two variables of block time (BT) and average horizontal force (AVYF).

The impulse-momentum relationship is another aspect of racing start performances that has been investigated by researchers. Payne & Blader (1971), referring to the running track start, stated that impulse was the most important kinetic variable to consider and that it is advantageous to produce the greatest amount of horizontal impulse possible. Hay (1985) noted that the force-time relationship of impulse and momentum played an important role in several sports skills, which included racing starts used in swimming and running. These and other researchers have identified additional advantages and have therefore recognized the importance of optimizing horizontal impulse [and horizontal velocity] in racing start performances (Payne & Blader, 1971; Ayalon et al., 1975; Hay & Guimaraes, 1983).

In this study, no significant difference was found for the dependent variable of horizontal impulse (YI) as a function of the swimming start used. However, the earlier significant findings for mean block time (BT) and mean average horizontal force (AVYF) values across the two techniques provide important information for interpreting the horizontal impulse (YI) data. Although the mean horizontal impulse (YI) values achieved by swimmers using the grab start were approximately equal to the values achieved by performers using the track start (264.91 N·s and 269.75 N·s, respectively) what is crucial is the fact that the same impulse was produced in less time.

Miller and Nelson (1973) explain that "an increase in the impulse of the reaction force can be accomplished either by increasing the magnitude of the force or [increasing] the time over which it [the force] acts (p. 61)." The findings of this investigation can be interpreted in light of the above explanation. In the present study swimmers using the track start had faster starting times (BT, M = 0.769s) and generated more horizontal force (AVYF, M = 391.6 N) when compared to their grab start performances (M = 0.833s and M = 354.2 N, respectively).

The above findings are clearly illustrated when the horizontal F-t (Force-time) curves are compared (see Figure 29). These F-t curves were generated using the horizontal force data for one grab start trial and for one track start trial. Horizontal force values are represented by the "y" axis and movement time corresponds with the "x" axis.

The values achieved by this subject, in Figure 29, for one trial using each starting technique demonstrated significant differences across the three dependent variables of block time (BT), average horizontal force (AVYF) and

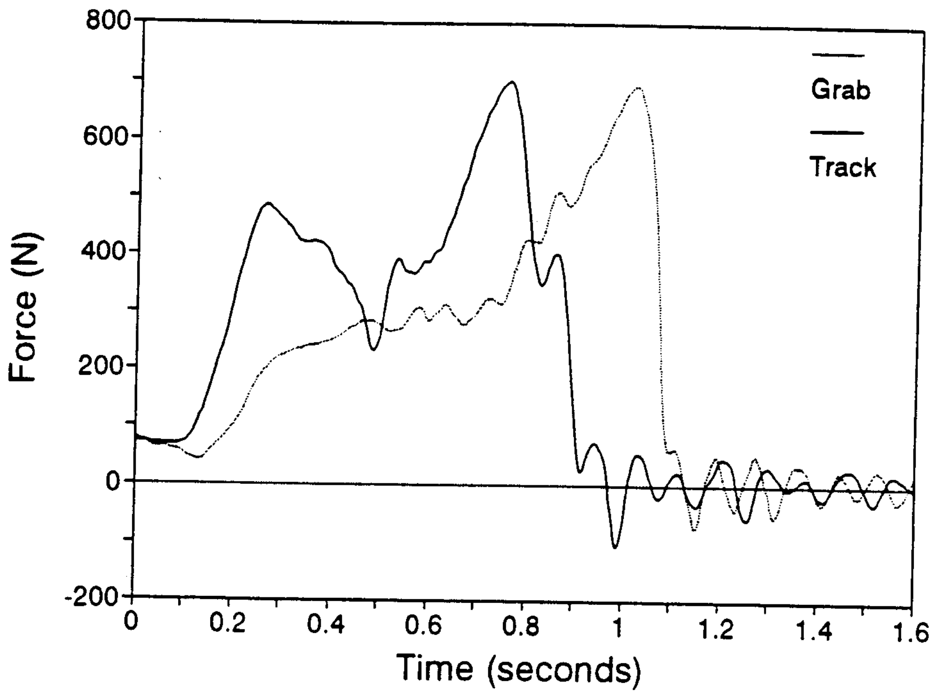

Figure 29. Horizontal Force-time (F-t) curves for one grab and one track start trial by the same subject.

horizontal impulse (YI). The subject obtained a block time (BT) value of 0.732s for the track start trial and a value of 0.904s for the grab start trial. Values for movement time (MT), used to compute the impulse values, are also presented. The respective values achieved for movement time (MT) for the track and grab start trial were 0.652s and 0.804s. Block time (BT) and movement time (MT) values achieved for the track start trial were significantly less that the values achieved for the grab start trial. Significant difference in average horizontal force (AVYF) values were also demonstrated for the same track and grab start trials, 393.7 N and 319.2 N, respectively.

In contrast to the above observed differences, the swimmer achieved a horizontal impulse (YI) value for the track start trial (256.7 N·s) that was equivalent with the value obtained for the grab start trial (256.6 N·s). It is important to note that while the horizontal impulse (YI) values were similar for the grab and track starts (i.e., 256.6 and 256.7 N·s, respectively), the block time (BT), movement time (MT) and average horizontal force (AVYF) values differed significantly between the two techniques. These findings demonstrated that swimmers using the track starting technique were able to generate greater horizontal force in less time and meet the criterion for determining a more effective starting style.

A review of the mean vertical impulse (ZI) values achieved for each starting technique also provided support for the hypothesis that swimmers using the more effective track starting style would achieve vertical impulse (ZI) values that were significantly lower when compared to those achieved when using the grab start. The negative values obtained indicated that for both starting techniques, the resultant force (ground reaction minus subject weight) was acting in a negative direction, resulting in downward motion. Figure 30 illustrates a typical vertical F-t curve for one grab and one track start trial for the same subject.

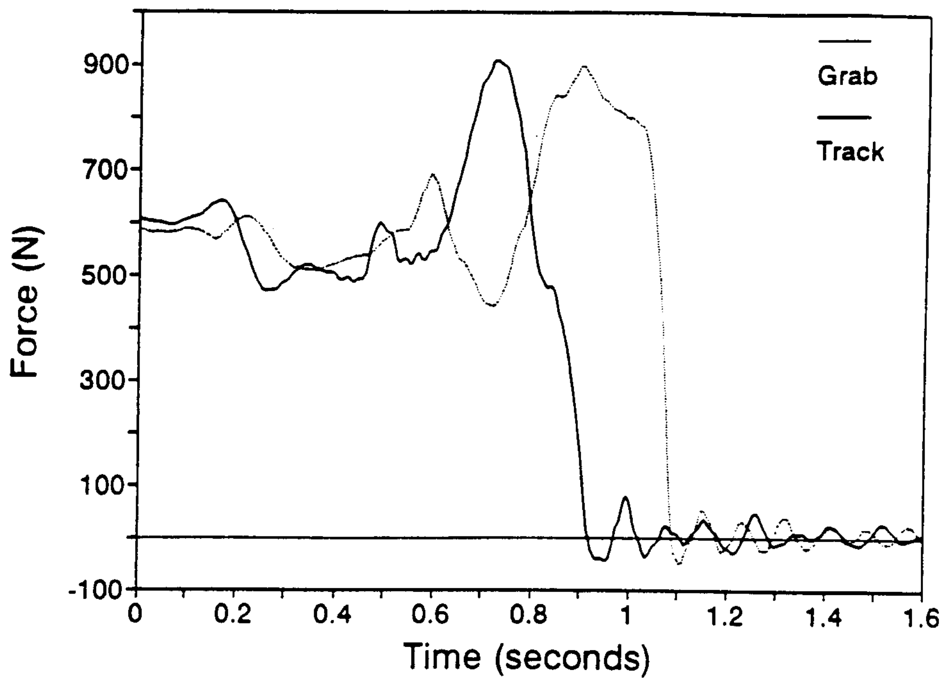

Figure 30. Vertical Force-time (F-t) curves for one grab and one track start trial by the same subject.

Further interpretation of the findings for vertical impulse (ZI) was provided by reviewing the results obtained in the comparison of block time (BT) and average vertical force (AVZF) values between the two techniques. This interpretation is similar to the earlier explanation presented for the F-t components of horizontal (YI).

A lower impulse can be achieved either by decreasing the magnitude of the applied force or by decreasing the time over which the force is applied [less time]. In this study the results for the comparison of block time (BT) between the two starting techniques indicated that swimmers study the results for the comparison of block time (BT) between the two starting techniques indicated that swimmers performing the track start left the block faster when compared with using the grab start. In other words, performers using the grab start had slower starting times, indicating that the component of time was not decreased to obtain a lower impulse. Therefore, based upon the findings for the comparison of block time (BT) values between the two techniques, the F-t relationship allows for only one interpretation -- that the magnitude of the average vertical force (AVZF) values must be less when swimmers used the grab start when compared with their track start performances.

In addition to the above, and also based upon the statistical findings for the comparison of vertical impulse (ZI) and block time (BT) values between the two techniques, it was predicted that significant difference would be found for the comparison of mean average vertical force (AVZF) values between the grab and track starting techniques.

The results of the statistical analysis revealed that swimmers using the track style start achieved mean average vertical force (AVZF) values that were significantly less when compared to those related to use of the grab start technique. These findings indicate yet another advantage associated with the use of the track start, which is the swimmer's ability to generate lower average vertical force (AVZF).

The ability to accelerate [rate at which velocity changes] more quickly and to achieve higher velocity values is another aspect of racing start performance that has been investigated and compared between different starting techniques. Several researchers compared different starting techniques by analyzing velocity at takeoff and/or at water entry (Bowers and Cavanagh, 1975; Ayalon et al., 1975; Thorsen, 1975; Yoshida and Saito, 1981; Hay and Guimaraes, 1983; Nutzel and Thoma, 1986). One group of authors (Ayalon, Van Gheluwe and Kanitz, 1975; Counsilman, 1984) concur that maintaining the CM in a lower position during the force-production phase of a start contributes to a swimmer's ability to achieve greater horizontal acceleration [velocity] and less vertical velocity at takeoff. This results in the swimmer being able to enter the water in less time.

In the present study, statistical analysis determined significant differences between mean values for vertical velocity at takeoff (ZV) achieved by swimmers using the track starting technique when compared with their grab start performances. Based upon the negative values obtained for vertical impulse (ZI) and average vertical force (AVZF), it was further expected that vertical velocity (ZV) values would also be negative.

A comparison of mean vertical velocity (ZV) values for each starting technique yielded two important findings.

First, swimmers performing the track start achieved mean values for vertical velocity at takeoff (ZV) that were less when compared with their performances using the grab start, and, second, the actual vertical velocity (ZV) values obtained were negative, indicating that movement was in a downward direction. The fact that the magnitude of the negative values achieved were greater when swimmers used the track start, as compared with their grab start performances, further indicated that the downward movement achieved greater downward velocity. Swimmers using the track start achieved greater downward speed.

Average horizontal velocity during flight (AVYV) was another variable compared between the two starting techniques. Referring to the impulse-momentum relationship, Miller and Nelson (1973) write: "To achieve an effective take-off velocity...an athlete must be able to generate a substantial impulse from the ground reaction force" (p. 61). Hay (1986) further states that "horizontal speed at takeoff is determined in accord with the Impulse-momentum relationship and the horizontal impulse exerted upon [the athlete] in reaction to the forces he exerts upon the block (p. 78)." Due to the approximately equal values obtained for horizontal impulse (YI) by swimmers using both starting techniques, and based upon the above relationship between impulse and velocity, no significant difference was expected or evident when average horizontal velocity during flight (AVYV) was compared across the two starting techniques.

In this investigation, no significant difference was found for the variable of mean average horizontal velocity (AVYV) between swimmers using either the track start or the grab start. However, it is important to note that swimmers using the track start reached the point of takeoff and achieved their takeoff velocity in less time when compared with their performances using the grab starting technique. These results illustrate the important relationship between the kinetic and kinematic components and provide new information in the comparison of the two most currently used swimming racing starts.

Another important aspect of racing start performance that has been investigated by many researchers is the comparison of vertical and horizontal displacement of CM between different starting techniques (Hanauer, 1967; Roffer, 1971; Bowers, 1973; Guimaraes and Hay, 1985; Counsilman et al., 1988). In this investigation, no significant difference was evident for vertical displacement of CM (ZDCM) as a function of starting technique. The non-significant finding was attributed to several factors.

First, the existence of rather large differences in height between the subjects (162.0 to 174.0 cm, $\underline{M}$ = 168.1 cm), which were not accounted for in the analysis of the data, confounded the results and the ability to accurately compare performances between techniques (see Table A-1, Appendix A).

Another explanation for the lack of significant findings for vertical displacement (ZDCM) may be found in data that compared the vertical location of the CM at takeoff for the grab start and track start techniques (Table G-4). The data indicated that swimmers using both starting styles achieved approximately equal values for the vertical location of the CM at the point of takeoff. Based upon these findings, that the values obtained for the vertical location of the CM at takeoff were almost equivalent for both starting techniques, the method used to compute the vertical displacement of CM (ZDCM) values (measured from *takeoff* to water entry) had limited ability to determine differences between the two techniques for this dependent variable. A more meaningful evaluation of starting performance may have been to compute the vertical displacement of the CM (ZDCM) from the highest point after hand release to water entry.

In summary, statistical analysis for the dependent variable of vertical displacement of CM from takeoff to water entry (ZDCM) indicated no significant difference to exist between the two starting techniques. This finding was attributed to the existence of high subject variability and may also be in part due to the method chosen for computing the variable.

Comparison of horizontal displacement of CM between starting techniques was another variable investigated. When striving to achieve maximum horizontal displacement in a racing start performance, Kriegsbaum and Barthels (1985) recommend that an athlete "increase the time in the air but not sacrifice too much horizontal velocity since the diver also should strive for the greatest horizontal distance before entering the water" (p.367). Hay (1985) comments further that, "any performer who wishes to alter [or increase] the time of flight...must somehow increase... vertical velocity" (pp.33-36). Another factor contributing to displacement is the forces responsible for movement. If the objective is to achieve maximum horizontal distance, Miller and Nelson (1976) state that, "both horizontal and vertical components of force are required since the body must have sufficient time in the air to permit unimpeded horizontal movement" (p. 77).

Given the above, and the fact that a swimmer's trajectory is determined at takeoff, one explanation for the lack of significant findings for horizontal displacement may be found in the results for vertical velocity (ZV). These findings, in conjunction with the findings for average vertical force (AVZF), determined that swimmers using the track start had greater downward speed when compared with using the grab start. This indicated that when swimmers used the track start they did not achieve vertical velocity or vertical force sufficient enough to alter or increase flight time and thus attain greater horizontal distance.

Another explanation for the lack of significant findings for the comparison of horizontal displacement may be related to the lack of significant findings for the comparison of average horizontal velocity (AVYV). Horizontal displacement is partially dependent upon speed. Achieving greater speed will result in greater horizontal displacement. In this study, when swimmers used the track start they achieved greater downward speed and approximately equal horizontal speed when compared with their grab start performances.

In light of the above findings, that the conditions necessary for a performance to achieve maximum horizontal displacement (optimization of air/flight time, upward speed, and horizontal speed) were not determined for track start performances, no significant difference was evident when mean values for horizontal displacement of CM (YDCM) were compared across the two starting techniques.

In summarizing the results and discussion, the research hypotheses predicted that swimmers who used the track start, as the more effective starting technique, would achieve significantly higher ($p < 0.01$) mean values for four dependent variables (YI, AVYF, AYDM, and AVZV) and would achieve significantly lower mean values for the remaining five dependent variables (ZI, AVZF, BT, ZDCM, and ZV).

Significant difference, supporting the original hypotheses, was determined across five of the nine dependent variables, three kinetic (AVYF, ZI, and AVZF) and two kinematic (BT and ZV).

Based upon the results for average horizontal force (AVYF) and block time (BT), the interpretation of the findings for horizontal impulse (YI), though not statistically significant, were important in further determining the track start to be the more effective starting technique.

Statistical analysis approaching significance ($p = 0.015$) was determined for horizontal displacement of Center of Mass (YDCM).

No significant difference was found for average horizontal velocity (AVYV, $p = 0.322$). An interpretation for these findings was based upon the Impulse-Momentum relationship and the lack of significant difference found for horizontal impulse (YI), and the fact that takeoff velocity (AVYV) is dependent upon the ability to generate reasonably large horizontal impulse (YI).

No significant difference was determined for vertical displacement of Center of Mass (ZDCM). Lack of significant difference was attributed to variability in subject height, not accounted for prior to analysis, and also due to the method used to compute the vertical displacment (ZDCM) values.

CHAPTER V
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

In the kinetic and kinematic comparison of the grab and track starts used in competitive swimming it was hypothesized that the track start would be the more effective starting technique across nine dependent variables. Many earlier researchers have used kinematic variables to compare conventional and grab start performances (ie. Winter, 1968; Roffer, 1971; Havriluk,1972; McCutchan, 1973; Kirner et al., 1989). Previous investigations have largely compared only kinematic variables between different starting styles or have analyzed only one starting technique. In the few studies where kinetic components were considered no single study compared only the track and grab starting techniques, currently the two starts most widely, if not exclusively, used in competitive swimming. Furthermore, no single study has been conducted that compared track and grab start performances and considered both kinetic and kinematic variables.

This study analyzed the effectiveness of grab and track start performances in a comparison of four kinetic and five kinematic variables. The design and findings of this study do not replicate any previous research comparing competitive swimming start techniques. Ten subjects participated in this study. Each subject performed three trials of the grab start and three trials of the track start, in randomized order. The mean values for each of the nine dependent variables were analyzed using 2 x 10 (starting technique x subject) repeated measures Analyses of Variance.

The research hypotheses predicted that swimmers using the track start, as the more effective starting technique, would achieve significantly ($p < 0.01$) higher mean values for four dependent variables: horizontal impulse (YI), average horizontal force (AVYF), average horizontal velocity during flight (AVYV), and horizontal displacement of CM from takeoff to water entry (YDCM). Correspondingly, it was also hypothesized that swimmers performing the track start would achieve significantly lower mean values for the remaining five dependent variables: vertical impulse (ZI), average vertical force (AVZF), block time (BT), vertical velocity at takeoff (ZV), and vertical displacement of CM from takeoff to water entry (ZDCM). Location of CM data, presented in six different tables (see Appendix G), provided additional information for evaluating starting performance and was used to further explain the statistical findings.

Conclusions

Significant difference ($p < 0.01$) between the two starting styles was found for five of the nine dependent variables. These differences were determined for three kinetic variables: average horizontal force (AVYF), vertical impulse (ZI), and average vertical force (AVZF). Statistical analysis also determined significant difference between the two starting techniques for two kinematic variables: block time (BT) and vertical velocity (ZV). These findings supported the original hypotheses.

No significant difference was found in the comparison of horizontal impulse (YI) values. However, a review of the findings, based upon the Impulse-Momentum relationship, provided important information for comparing the two starting techniques. These findings did determine one starting style to be more effective than the other. Swimmers using the track starting technique achieved greater average horizontal force values (AVYF) and left the starting block faster when compared with their grab start performances. The inverse results were observed for swimmers using the grab starting technique: average horizontal force values (AVYF) were significantly less and block time (BT) values were significantly greater compared to the track start. Swimmers using both starting techniques attained almost equivalent values for horizontal impulse (YI). The crucial fact for interpreting the horizontal impulse data is that swimmers using the track start were able to produce greater force in less time. In light of this explanation the results are significant. These findings illustrate the Force-time relationship, and determined the track start to be the more effective starting style when compared with the grab start.

No main effect findings were observed for the remaining three dependent variables: horizontal displacement of CM (YDCM), vertical displacement of CM (ZDCM) and vertical velocity at takeoff (ZV).

Statistical results *approaching* significance ($p = 0.015$) were determined for the kinematic variable of horizontal displacement of CM from takeoff to water entry (YDCM). Explanation for these findings was attributed to the relationship between the kinetic and kinematic variables and the lack of significant difference determined for horizontal impulse (YI). Further explanation was also provided by the fact that all subjects (except for one) had less experience using the track start compared with the grab technique.

Lack of significant findings for the dependent variable of average horizontal velocity ($p = 0.322$) was based upon the results obtained for horizontal impulse (YI) and the impulse-momentum relationship. The amount of takeoff velocity that an athlete achieves is directly dependent upon the athlete's ability to generate a reasonably large impulse (Miller & Nelson, 1973, p. 61). In other words, the same force applied over a longer period of time would achieve a greater velocity than the same amount of force applied over a short period of time (Physics, p.66). The non-significant results were expected based upon the findings for the comparison of horizontal impulse (YI) and average horizontal force (AVYF) between the two starting techniques, and are also due in part to relationship that exist between the forces (kinetic variables) and the resulting motion (kinematic variables).

Lack of significant findings ($p > 0.07$) for the dependent variable of vertical displacement of CM (ZDCM) across the two starting techniques were attributed several factors. One explanation was the existence of variability in height between the subjects that was not accounted for prior to the analysis of data. Location of CM data provided two possible interpretations, in addition to subject variability. First, location of CM data indicated that the vertical trajectory of the CM during the preparatory phase of the track start was positive, or slightly upward (Table G-3). In contrast, the trajectory of the CM in grab start performances was either in a negative direction (downward) or was less than the track start. Secondly, location of CM data further suggested that the vertical location of the CM at takeoff was almost equal for both techniques (Table G-4). These findings suggest that there is a change in the location of the CM from start signal to the highest point after hand release, however, by the point of takeoff the location of the CM was similar for both starting techniques.

In addition to the above nine dependent variables and location of CM data, consideration must be given to factors related to the official rules of competitive swimming. These include the "No False Start Rule" and the "Long Course Starting Procedure."

Within the last 5-10 years, all of the major organizations governing the sport of swimming (YMCA, USS, NCAA, NHSAA and FINA) have adopted the "No False Start Rule." Under this rule a swimmer who is charged with a false start is immediately eliminated from that particular event in which the false start occurred. The swimmer is not only ineligible to compete but also looses the opportunity to win team points in that event.

Based upon the above ruling, where a swimmer is immediately eliminated from competition when charged with a false start, it is more crucial than ever before for swimmers and coaches to select a starting technique that ensures maximum stability and which provides the most effective racing start performance. In over 18 years of observation as a coach, this researcher has never once seen a swimmer using the track start false start, although many swimmers using the grab start have been observed "false starting". The findings of the location of CM data in this study determined that track start performers achieved a more stable ready position than grab start performers, due to the location of the CM further back from the front edge of the starting block (see Table G-1). Further evidence supporting the track start as the more stable starting technique is provided by Maglischo (1993) who states that "the track start is clearly superior for preventing false starts (p. 547)."

A second rule adoption by official swimming organizations, and another factor to consider in the selection of a racing start, is the adoption of the long course starting procedure. The long course starting procedure, or rule, requires that all swimmers be positioned at the rear of the starting block immediately following the starter's command, "Swimmers to the blocks," and preceding the starter's command, "Swimmers take your mark." Once the command to "Take your mark" is given, swimmers must immediately assume the ready position and hold that position without any movement.

When performing the grab start a swimmer must move both feet in order to assume the ready position with the placement of both feet at the front edge of the starting block. In contrast, swimmers using the track start technique, need to move only one foot since the track start ready position requires that the rear foot be placed near the back edge of the starting block. Therefore, when using the track start technique swimmers need to move, or place, only one foot. This eliminates excessive movement, thereby minimizing the chance of being charged with a false start.

In light of the above adoption of rules, the track start has demonstrated advantages over other starting techniques.

Havriluk (1979), who investigated the Force-time relationship and its relevance to racing start performances used in competitive swimming, proposed that if less time were spent on the starting block then less impulse would be produced. Havriluk further hypothesized that if more time were spent on the starting block then the amount of impulse produced would be increased. Hay (1985), also referring to the impulse-momentum relationship, commented that "the swimmer's objectives (quickness off the starting block and maximum forward speed) are incompatible, for if the swimmer leaves the block as quickly as possible, the horizontal impulse developed is such that forward speed [velocity, force] is less than it could be. Conversely, if the time necessary to develop maximum horizontal impulse (and thus maximum horizontal speed) is taken, the swimmer will leave the block rather later than might otherwise be the case (p. 44)."

The findings of this study provided evidence contrary to the above researchers' predictions. This investigation determined that swimmers using the track style start achieved greater horizontal force (AVYF) values and in less time (BT) when compared with their grab start performances. Although no significant difference was found in the statistical analysis comparing mean values for horizontal impulse (YI) achieved by swimmers using both starting techniques, the above results are crucial in determining effectiveness of starting performance and therefore these finding determined the track start to be the more effective technique.

Subjective observation of racing starts for more than 15 years of collegiate, high school and/or age group coaching by this researcher prompted this investigation. The kinetic and kinematic design, statistical results and the qualitative findings of this study do not replicate any previous research comparing the two most currently used starting techniques in competitive swimming, the grab and track starts. The findings of this study provide new information to more effectively evaluate the effectiveness of racing start performance.

Recommendations

Based upon the results of this study the following recommendations for future studies are made:

1. The exact contribution of the arms to the total production of force in the track style start remains to be determined. Future research should be conducted with a design to separately measure the individual contribution of the hands and the feet to the total force produced. A combination of using the force platform with strain gauges may achieve such a design.

2. In addition to the dependent variables investigated in this study, it is recommended that future investigations of current racing starts incorporate a method similar to Hay's research (1986), to analyze the glide phase of a start performance. Touch pads, designed to measure accurately to 0.001th of a second, could be placed on a moveable bulkhead at a specified distance from the starting block. In this manner assessment of starting time while on the starting platform and analysis of the glide phase, which has been determined by some researchers to be one of the most important portions of the racing start, could both be considered.

3. In future studies of similar design, where grab and track start techniques are to be compared, greater efforts should be taken to ensure that all subjects are equally proficient in performing both techniques. It is recommended that future studies which compare the track style start to other starting styles provide at least one training and practice session to insure uniformity of technique between subjects. This researcher recommends teaching swimmers the track start technique where there is a counter-balance between the hands and the feet and where the weight is supported by the rear foot.

4. Future studies should consider whether or not there is a potential for using force platforms to detect anticipatory movement that is not visually detectible. In

this study anticipatory movement was detected from the force data for a majority of subjects. Further ramifications may exist for identifying such movement in a race situation and for determining whether or not such anticipatory movement, which is not visually detectible, constitutes a false start.

5. In conjunction with the variables presented in this study, comparison of the angle at takeoff and the angle at water entry would provide additional information to evaluate the effectiveness of different starting techniques.

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APPENDICES

APPENDIX A

Subject Information

Table A-1. Subject Information: Height and Weight.

	Height (centimeters)	Weight/Mass (Kilograms)
S1	162.0	58.1
S2	170.2	71.7
S3	172.7	75.3
S4	172.7	61.2
S5	174.0	76.9
S6	163.2	51.7
S7	162.6	58.5
S8	171.5	54.8
S9	166.4	62.7
S10	170.8	65.9
Mean =	168.1	63.7

Table A-2. Subject Information: Best time for 50 and 100 yd, number of years using grab and track starts, and age.

	Best Free Time (in seconds) 50 yds	100 yds	Number of Years Using Each Start Grab	Track	Age
S1	:23.69	:51.5	6	6*	21
S2	:24.78	:52.89	8	3-4*	20
S3	:27.4	:58.8	7*	1	19
S4	:28.4	:59.3	8	3-4*	21
S5	:24.73	:56.4	13	7*	20
S6	:26.10	----	2	5*	19
S7	:29.10	1:04.0	4	1*	20
S8	:25.95	:56.73	4	4*	16
S9	:24.68	:55.49	6	3*	16
S10	:25.02	:54.43	13*	4	20
Mean=	:26.04	:56.62	7.1	3.8	19.2

* Indicates the subject's preference of starting technique.

APPENDIX B

<u>Informed Consent Form</u>

OREGON STATE UNIVERSITY
Corvallis, Oregon

Subj#_____
CAJ/90

Title: A Kinetic and Kinematic Comparison of the Grab and Track Starts in Competitive Swimming

Investigator: Cheryl A. Juergens

I,______________________________ hereby agree to participate as a volunteer in a scientific investigation authorized through Oregon State University, under the supervision of Cheryl A. Juergens.

The supervisor has fully defined the investigation and explained my part in the investigation, and I understand her explanation. A copy of the procedures for the investigation and a description of the possible risks have been provided for me and have been fully discussed.

I have been provided the opportunity to ask any questions,and those questions have been answered to my satisfaction.

In the event of physical injury resulting from my participation in this investigation, I understand that neither free medical care nor financial compensation will be provided.

I certify that, to the best of my knowledge, I have no physical or mental illness that will increase the risk associated with my participation.

I clearly understand that I may withdraw from participation in this study at any time.

______________ ______________________________
(Date) (Subject's signature)

______________ ______________________________
(Date) (Parent/Guardian's signature)

I, the undersigned, certify that the conditions and procedures of this investigation have been defined and explained to the above subject.

______________ ______________________________
(Date) (Investigator's signature)

APPENDIX C

Subject Questionnaire

Subj#_____
CAJ/90

OREGON STATE UNIVERSITY
Corvallis, Oregon

1. Name:______________________ Age:________
2. Address:______________________________
3. Phone:______________ 4. Racing suit size:______
5. Height (cm):____________ 6. Weight (kg):__________
7. 50 yd free (LTB):________ 8. 100 yd free (LTB):______
9. Highest level achieved in competitive swimming:________
____
10. Have you used the grab style racing start?__________
If yes, for how long?____________________
11. Have you used the track style racing start?__________
If yes, for how long?____________________
12. What is the main start that you use competitively?_____
13. How long have you used your main competitive start?____
14. How were you introduced to or how did you learn the racing start that you currently use?
____
15. Why do you NOT use or NOT prefer the other style start?
____
16. What do you feel is the better racing style start and why?
____
17. What is/are your specialty event(s)? Give stroke and distance. ____________________
18. Distance from front of block to:
(a.) back foot toes:_______ (b.) back foot heel:_______
19. Distance from front foot heel to:
(a.) back foot toes:_______ (b.) back foot heel:_______
21. Other comments:__________________________
____

date:__________

APPENDIX D

Intraclass Reliability Coefficients for Original Thirteen Dependent Variables

Table D-1. Intraclass Reliability Coefficients for Original Six Kinetic Variables

DEPENDENT VARIABLE:	GRAB START	TRACK START
Horiz Impulse (YI)	.995	.994
Vert Impulse (ZI)	.888	.891
Aver Horiz Force (AVYF)	.968	.971
Aver Vert Force (AVZF)	.895	.898
Peak Horiz Force (PYF)	.972	.967
Peak Vert Force (PZF)	.964	.975

Table D-2. Intraclass Reliability Coefficients for Original Seven Kinematic Variables

DEPENDENT VARIABLE:	GRAB START	TRACK START
Block Time (BT)	.812	.781
Horiz Displ of CM (YDCM)	.962	.988
Vert Displ of CM (ZDCM)	.776	.905
Aver Horiz Vel (AVYV)	.914	.942
Vert Velocity (ZV)	.850	.852
Reaction Time (RT)	.091	.090
Movement Time (MT)	.871	.853

APPENDIX E

Correlation Matrix for Nine Dependent Variables and Body Mass

Table E-1. Correlation Matrix for Dependent Variables and Body Mass

	YI	Total ZI	AVYF	AVZF	YDCM	ZDCM	AVYV	ZV	BT	MASS
YI	1.0									
Total ZI	0.057	1.0								
AVYF	0.823	0.17	1.0							
AVZF	0.112	0.988	0.153	1.0						
YDCM	0.379	0.366	0.517	0.368	1.0					
ZDCM	0.261	0.536	0.331	0.572	0.586	1.0				
AVYV	0.214	0.085	0.431	0.04	0.691	-0.02	1.0			
ZV	0.202	0.708	0.204	0.738	0.279	0.557	-0.037	1.0		
BT	0.125	-0.225	-0.437	-0.113	-0.398	-0.206	-0.471	-0.002	1.0	
MASS	0.972	0.019	0.759	0.091	0.268	0.232	0.09	0.213	0.187	1.0

APPENDIX F

Eliminated Dependent Variables

Table F-1. Peak Horizontal Force (PYF)
(Newtons)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	744.75	779.93	815.72	659.27	677.78	625.72
S2	894.60	884.57	828.98	826.99	771.92	791.60
S3	824.80	833.07	845.78	684.68	715.73	696.1
S4	752.10	693.52	765.44	701.18	692.57	699.54
S5	967.55	998.73	970.76	902.69	868.39	953.50
S6	572.03	604.42	630.91	525.03	605.65	571.25
S7	799.49	776.34	756.94	614.91	578.06	592.33
S8	630.15	647.32	599.08	538.19	592.26	629.29
S9	687.76	744.58	762.28	669.86	668.31	752.61
S10	917.14	897.00	1027.53	719.04	672.52	702.46

Table F-2. Peak Vertical Force (PZF)
(Newtons)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	981.86	931.88	932.14	894.42	870.44	988.97
S2	1127.20	1195.87	1110.23	1110.21	956.43	1061.00
S3	1067.03	1045.88	1010.42	977.46	996.97	962.10
S4	969.72	898.22	877.98	909.68	948.10	911.45
S5	1397.76	1433.75	1428.39	1292.37	1282.74	1292.76
S6	777.97	850.55	836.47	741.15	844.21	810.80
S7	876.36	852.95	947.71	861.25	802.26	803.27
S8	857.78	924.69	806.17	725.09	754.42	801.30
S9	873.98	809.21	772.29	902.00	881.39	910.84
S10	1021.70	1015.82	1245.05	1073.79	1056.77	1035.47

Table F-3. <u>Reaction Time (RT)</u>
(seconds)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.080	0.088	0.056	0.092	0.136	0.080
S2	0.068	0.088	0.112	0.116	0.064	0.012
S3	0.056	0.064	0.108	0.052	0.128	0.004*
S4	0.024	0.100	0.096	0.080	0.080	0.112
S5	0.024	0.016	0.076	0.088	0.092	0.044
S6	0.104	0.116	0.120	0.032	0.104	0.108
S7	0.060	0.108	0.112	0.024	0.028	0.064
S8	0.136	0.124	0.084	0.108	0.112	0.076
S9	0.116	0.760	0.032	0.080	0.084	0.048
S10	0.120	0.028	0.124	0.092	0.036	0.072

* From force tracings there was movement at the start signal which indicated a false start.

Table F-4. Movement Time (MT)
(seconds)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.756	0.748	0.784	0.628	0.628	0.656
S2	0.720	0.780	0.760	0.640	0.700	0.592
S3	0.844	0.832	0.900	0.852	0.788	0.864
S4	0.804	0.804	0.860	0.652	0.732	0.704
S5	0.780	0.740	0.716	0.640	0.640	0.700
S6	0.712	0.704	0.688	0.776	0.688	0.692
S7	0.788	0.784	0.768	0.652	0.788	0.716
S8	0.644	0.640	0.696	0.656	0.600	0.612
S9	0.712	0.676	0.660	0.652	0.656	0.668
S10	0.668	0.816	0.680	0.724	0.732	0.780

APPENDIX G

Location of CM During Start Performance

Table G-1. **Horizontal Location of CM in Ready Position (meters)**

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.080	0.064	0.061	0.207	0.234	0.233
S2	0.095	0.101	0.099	0.139	0.124	0.160
S3	0.075	0.085	0.115	0.348	0.382	0.343
S4	0.129	0.143	0.130	0.286	0.286	0.268
S5	0.183	0.164	0.195	0.323	0.333	0.346
S6	0.110	0.122	0.140	0.184	0.193	0.217
S7	0.159	0.161	0.165	0.365	0.388	0.360
S8	0.091	0.105	0.092	0.119	0.096	0.063
S9	0.135	0.133	0.121	0.402	0.405	0.386
S10	0.115	0.139	0.102	0.355	0.346	0.301

Table G-2. **Vertical Location of Center of Mass in Ready Position (meters)**

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.560	0.590	0.591	0.551	0.586	0.559
S2	0.678	0.634	0.609	0.588	0.581	0.600
S3	0.589	0.572	0.542	0.562	0.560	0.568
S4	0.584	0.581	0.552	0.563	0.528	0.566
S5	0.583	0.596	0.573	0.540	0.521	0.537
S6	0.581	0.558	0.561	0.556	0.571	0.567
S7	0.561	0.559	0.543	0.511	0.490	0.513
S8	0.570	0.565	0.576	0.569	0.567	0.579
S9	0.533	0.523	0.500	0.501	0.492	0.490
S10	0.612	0.582	0.593	0.584	0.596	0.605

Table G-3. **Vertical Displacement of CM from Ready Position to Highest Point After Hand Release (meters)**

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	-0.006	-0.078	-0.050	0.035	0.035	0.035
S2	-0.007	-0.003	-0.068	0.015	0.029	0.039
S3	-0.070	-0.024	-0.095	0.034	0.040	-0.013
S4	0.026	0.035	-0.001	0.033	0.114	0.061
S5	0.088	0.141	0.148	0.224	0.243	0.184
S6	0.037	0.044	0.021	0.024	0.021	0.036
S7	-0.004	0.015	0.043	0.139	0.132	0.131
S8	0.076	0.080	0.009	0.096	0.109	0.067
S9	0.012	-0.025	-0.078	0.077	0.111	0.053
S10	0.021	-0.002	-0.005	0.133	0.088	0.110

Table G-4. **Vertical Location of CM at Takeoff (meters)**

(Vertical Location of CM in Ready Position)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	**0.554** (0.56)	**0.510** (0.59)	**0.541** (0.591)	**0.581** (0.551)	**0.603** (0.586)	**0.583** (0.559)
S2	**0.671** (0.678)	**0.631** (0.634)	**0.543** (0.609)	**0.586** (0.588)	**0.609** (0.581)	**0.639** (0.60)
S3	**0.518** (0.589)	**0.538** (0.572)	**0.405** (0.542)	**0.576** (0.562)	**0.558** (0.56)	**0.509** (0.568)
S4	**0.601** (0.584)	**0.614** (0.581)	**0.550** (0.552)	**0.588** (0.563)	**0.641** (0.528)	**0.625** (0.566)
S5	**0.668** (0.583)	**0.704** (0.596)	**0.704** (0.573)	**0.753** (0.54)	**0.753** (0.521)	**0.709** (0.537)
S6	**0.618** (0.581)	**0.602** (0.558)	**0.579** (0.561)	**0.572** (0.556)	**0.579** (0.571)	**0.591** (.567)
S7	**0.512** (0.561)	**0.540** (0.559)	**0.586** (0.543)	**0.646** (0.511)	**0.607** (0.49)	**0.638** (0.513)
S8	**0.647** (0.57)	**0.637** (0.565)	**0.579** (0.576)	**0.666** (0.569)	**0.672** (0.567)	**0.643** (0.579)
S9	**0.545** (0.533)	**0.498** (0.523)	**0.415** (0.50)	**0.576** (0.501)	**0.596** (0.492)	**0.533** (0.49)
S10	**0.632** (0.612)	**0.582** (0.582)	**0.589** (0.593)	**0.717** (0.584)	**0.683** (0.596)	**0.699** (0.605)

Table G-5. **Time Elapsed from Point Where Vertical Location of CM is Even With Front Edge of Starting Block to Water Entry (sec)**

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.850	0.833	0.833	0.680	0.663	0.680
S2	0.850	0.867	0.816	0.731	0.799	0.697
S3	0.884	0.901	0.850	0.714	0.697	0.697
S4	0.884	0.867	0.884	0.748	0.748	0.731
S5	0.833	0.867	0.850	0.765	0.748	0.731
S6	0.833	0.867	0.816	0.748	0.765	0.731
S7	0.816	0.782	0.833	0.723	0.689	0.680
S8	0.850	0.867	0.833	0.782	0.765	0.774
S9	0.884	0.859	0.833	0.680	0.680	0.689
S10	0.850	0.816	0.833	0.740	0.748	0.748

Table G-6. **Vertical Displacement of CM from Even With Front Edge of Starting Block to Water Entry (meters)**

(from highest point after hand release to water entry)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	**0.941** (0.942)	**0.847** (0.788)	**0.803** (0.761)	**0.747** (0.806)	**0.796** (0.851)	**0.762** (0.817)
S2	**0.798** (0.809)	**0.763** (0.771)	**0.725** (0.68)	**0.771** (0.817)	**0.793** (0.858)	**0.620** (0.705)
S3	**0.783** (0.742)	**0.735** (0.73)	**0.713** (0.645)	**0.831** (0.871)	**0.779** (0.821)	**0.806** (0.821)
S4	**0.722** (0.765)	**0.750** (0.822)	**0.801** (0.84)	**0.870** (0.924)	**0.769** (0.891)	**0.787** (0.509)
S5	**0.809** (0.901)	**0.818** (0.961)	**0.768** (0.913)	**0.797** (0.986)	**0.816** (1.018)	**0.845** (0.998)
S6	**0.929** (0.965)	**0.886** (0.923)	**0.900** (0.918)	**0.906** (0.917)	**0.907** (0.909)	**0.880** (0.894)
S7	**0.976** (0.931)	**0.867** (0.869)	**0.890** (0.918)	**0.856** (0.955)	**0.847** (0.934)	**0.830** (0.925)
S8	**0.836** (0.91)	**0.749** (0.822)	**0.792** (0.806)	**0.676** (0.796)	**0.685** (0.799)	**0.783** (0.884)
S9	**0.960** (0.979)	**0.834** (0.833)	**0.876** (0.815)	**0.876** (0.924)	**0.894** (0.965)	**0.898** (0.932)
S10	**0.800** (0.827)	**0.755** (0.763)	**0.753** (0.762)	**0.702** (0.806)	**0.805** (0.864)	**0.794** (0.887)

APPENDIX H

Application for Approval of the Human Subjects Board

Description of Methods and Procedures:

The primary purpose of this study is to compare the kinematic and kinetic components of the grab and track style racing starts in competitive swimming.

The subjects selected for this study will be 12 female varsity swimmers, ages 15-23, who use both starting techniques interchangeably in competition. The subjects will volunteer to participate in one data collection session of approximately one hour in length at the Langton Hall swimming pool on the Oregon State University campus. Each swimmer will have eleven anatomical landmarks marked with a felt marker and will then be video-taped as she executes three trials of each start. The starting technique for each trial will be randomly presented.

The video data will be digitized and analyzed using the Peak 2D, Motion Measurement System (a video analysis system designed by Peak Performance Technologies, Incorporated). Reaction force components will be directly obtained from a Kistler force plate. Reaction time, the ratio of horizontal to vertical impulse and average force values were obtained in subsequent analysis of the force-time curves.

The Kistler force platform was mounted to the Paragon starting block by the OSU Mechanical Engineering Department, under the direction and supervision of professor Clarence C. Calder. The top or starting surface is the original Paragon or manufacturer's starting surface. The Paragon starting block has been professionally installed in the Langton Hall natatorium in accordance with the manufacturer's instructions. Specific modifications to the height of the Paragon starting block were completed by the manufacturer prior to the block's shipment to OSU. Details of the installation and modifications are available through the Department of Exercise and Sport Science accounting office (Tri Schodorf: ext. 3174).

Force data will be recorded for each trial by the Kistler amplifier. The force data will then be transferred to an IBM compatible computer that is interfaced with the Kistler force platform and amplifier.

NOTE: There is no danger of electrical shock to the subject from the forceplate and connecting wires due to the extremely low, or safe, level of voltage output.

APPENDIX H (CONTINUED)

Risks/Benefits to Subjects:

There are no perceived risks to the subjects. Benefits to the subjects will include receiving individual feedback on their performance plus the opportunity to participate in research designed to further the understanding and knowledge of kinetic and kinematic variables in speed swimming starts.

Informed Consent Form:

A copy of the Informed Consent Form is attached. Subjects will be given a copy of the Informed Consent Form prior to the data collection session and will be asked to return the completed form to the investigator before participating in this study.

Anonymity:

Each subject will randomly be assigned a number (e.g., S1, S2, S3, etc.). Data will be recorded and analyzed by subject number. Only the researcher will have access to all records. All records linking subject names to the subject numbers will be discarded following completion of the study.

Questionnaire:

A questionnaire will be used to obtain information pertinent to the study. A copy of this questionnaire is attached.

Outside Funding:

This project is not part of a proposal to an outside funding agency.

Dr. Phillip Sperber, President of KDI Paragon Incorporated, donated one standard Paragon starting platform.

Mr. Graham Scott, of Ocean Pool Supply, donated 12 female lycra racing swim suits to this research. The suits were a light color so that the anatomical landmarks, placed on each subject with black magic marker, would be most visible when the data was analyzed.

APPENDIX I

Kinetic Data Tables Not Included in Chapter IV

Table I-1. **Horizontal Impulse (YI)**
(Newton• seconds)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	246.360	246.561	247.335	253.501	262.843	257.103
S2	293.500	303.070	311.276	305.266	293.591	294.777
S3	315.855	314.936	320.456	326.584	316.887	319.000
S4	250.751	256.636	270.155	256.710	264.457	269.154
S5	342.350	327.364	331.455	342.683	341.922	358.879
S6	198.582	200.429	201.786	207.959	203.813	205.078
S7	247.550	247.872	242.708	242.878	255.309	248.197
S8	214.871	211.041	221.513	215.990	215.435	213.493
S9	260.345	261.115	260.278	279.926	278.317	278.486
S10	260.515	269.699	270.876	261.273	254.049	269.063

Table I-2. **Vertical Impulse (ZI)**
(Newton• seconds)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	-29.6	-38.2	-42.2	-42.6	-55.6	-52.1
S2	-12.0	-33.8	-38.5	-33.8	-51.4	-24.2
S3	-26.4	-23.7	-79.3	-71.3	-67.5	-58.4
S4	- 5.2	- 9.5	-16.9	-19.2	- 5.7	-18.7
S5	22.1	42.6	38.0	20.3	16.5	- 0.1
S6	-10.2	- 5.5	-12.7	-37.8	-25.1	-28.5
S7	-18.5	-17.4	- 2.2	-25.0	-30.1	-27.8
S8	0.4	2.0	-13.7	- 9.9	-18.8	-19.3
S9	- 6.8	-10.5	-20.5	-25.1	-27.8	-68.0
S10	-66.9	-21.1	-76.8	-59.6	-22.8	-52.3

Table I-3. **Average Horizontal Force (AVYF)**
(Newtons)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	325.874	329.627	315.478	403.664	418.540	391.925
S2	407.600	388.552	409.573	476.978	419.415	497.934
S3	374.236	378.529	356.062	383.315	402.140	369.200
S4	311.880	319.199	314.134	393.727	361.282	382.321
S5	438.911	442.384	462.927	535.443	534.253	512.685
S6	278.907	284.701	293.294	267.988	296.240	296.355
S7	314.200	316.200	316.000	372.512	323.996	346.644
S8	333.651	329.752	318.266	329.253	359.059	348.845
S9	365.653	386.265	394.361	429.334	424.264	416.895
S10	389.992	330.514	398.347	360.874	347.062	344.953

Table I-4. **Average Vertical Force (AVZF)**
(Newtons)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	-39.1	-51.1	-53.9	-67.9	-88.6	-79.4
S2	-16.7	-43.4	-50.6	-52.8	-73.4	-40.9
S3	-31.2	-28.5	-88.1	-83.6	-85.6	-67.6
S4	- 6.5	-11.8	-19.7	-29.5	- 7.7	-26.5
S5	28.3	57.5	53.0	31.7	25.8	- 0.1
S6	-14.3	- 7.9	-18.4	-48.7	-36.5	-41.2
S7	-23.4	-22.2	- 2.9	-38.3	-38.2	-38.9
S8	0.6	3.2	-19.6	-15.0	-31.3	-31.6
S9	- 9.5	-15.5	-31.0	-38.5	-42.4	-95.0
S10	-84.9	-25.0	-95.6	-73.0	-29.7	-61.4

APPENDIX J

Kinematic Data Tables Not Included in Chapter IV

Table J-1. **Block Time (BT)**
(seconds)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.836	0.836	0.84	0.720	0.764	0.736
S2	0.788	0.868	0.872	0.756	0.764	0.604
S3	0.900	0.896	1.008	0.904	0.916	0.868
S4	0.828	0.904	0.956	0.732	0.812	0.816
S5	0.804	0.756	0.792	0.728	0.732	0.744
S6	0.816	0.820	0.808	0.808	0.792	0.800
S7	0.848	0.892	0.880	0.676	0.816	0.780
S8	0.780	0.764	0.780	0.764	0.712	0.688
S9	0.828	0.752	0.692	0.732	0.740	0.716
S10	0.788	0.844	0.804	0.816	0.768	0.852

Table J-2. **Horizontal Displacement of CM (YDCM)** (meters)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	2.75	2.57	2.56	2.70	2.76	2.76
S2	2.70	2.72	2.56	2.66	2.70	2.57
S3	2.54	2.55	2.47	2.86	2.87	2.75
S4	2.73	2.78	2.82	2.94	2.93	2.86
S5	3.07	3.14	3.12	3.26	3.26	3.28
S6	2.66	2.66	2.68	2.72	2.73	2.70
S7	2.86	2.76	2.85	3.10	3.05	2.98
S8	2.82	2.77	2.70	2.69	2.58	2.63
S9	3.03	2.97	2.88	3.21	3.25	3.23
S10	2.82	2.77	2.78	2.95	3.03	2.90

Table J-3. **Vertical Displacement of CM (ZDCM)**
(meters)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	1.64	1.55	1.49	1.54	1.57	1.52
S2	1.46	1.53	1.53	1.52	1.56	1.41
S3	1.57	1.48	1.48	1.59	1.54	1.58
S4	1.52	1.48	1.48	1.59	1.54	1.58
S5	1.61	1.73	1.78	1.81	1.77	1.74
S6	1.61	1.60	1.61	1.57	1.54	1.53
S7	1.60	1.52	1.61	1.63	1.57	1.64
S8	1.62	1.55	1.53	1.59	1.56	1.67
S9	1.58	1.45	1.47	1.52	1.55	1.52
S10	1.62	1.54	1.56	1.62	1.68	1.71

Table J-4. **Average Horizontal Velocity (AVYV)**
(meters/second)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	3.88	4.02	3.95	4.04	4.12	3.92
S2	3.95	3.98	4.05	4.14	4.04	4.05
S3	3.74	3.77	3.86	3.98	3.99	3.92
S4	3.84	3.83	3.95	3.96	3.90	4.02
S5	4.09	4.09	4.06	4.20	4.16	4.23
S6	3.73	3.80	3.86	3.96	3.94	3.89
S7	4.21	4.39	4.04	4.29	4.32	4.22
S8	4.12	3.92	4.02	3.87	3.87	3.82
S9	4.21	4.32	4.37	4.53	4.53	4.56
S10	4.17	4.07	4.14	3.94	4.03	3.54

Table J-5. **Vertical Velocity at Takeoff (ZV)**
(meters/second)

	GRAB			TRACK		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
S1	0.12	-0.23	-0.07	-0.34	-0.24	-0.59
S2	0.15	0.10	-0.08	-0.51	-0.14	-0.39
S3	-0.20	-0.36	-0.79	-0.58	-0.54	-0.78
S4	0.48	0.25	0.18	-0.53	-0.15	-0.22
S5	0.33	0.74	0.63	0.50	0.42	0.34
S6	0.01	0.00	-0.10	-0.44	-0.23	-0.13
S7	-0.14	-0.02	-0.03	-0.14	-0.72	-0.43
S8	0.13	0.34	-0.37	-0.04	-0.24	-0.30
S9	-0.01	0.08	-0.45	-0.21	-0.45	-0.61
S10	0.16	0.19	0.10	-0.05	-0.20	0.20

APPENDIX K

Subject Data Tables Not Included in Chapter IV

Table K-1. **Subject 1. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	SD	TRACK START Mean	SD
Horiz. Impulse (YI)	246.8	0.5	257.8	4.7
Vert. Impulse (ZI)	-36.7	6.5	-50.1	6.7
Aver. Horiz. Force (AVYF)	323.7	7.3	404.7	13.3
Aver. Vert. Force (AVZF)	-48.0	7.8	-78.6	10.4
Block Time (BT)	0.837	0.002	0.740	0.022
Horiz. Displ. (YDCM)	2.63	0.11	2.74	0.03
Vert. Displ. (ZDCM)	1.56	0.08	1.55	0.02
Aver. Horiz. Velocity (AVYV)	3.95	0.07	4.03	0.10
Vertical Velocity (ZV)	-0.06	0.18	-0.39	0.18

Table K-2. **Subject 2. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	SD	TRACK START Mean	SD
Horiz. Impulse (YI)	302.6	8.9	297.9	6.4
Vert. Impulse (ZI)	-28.1	14.1	-36.4	13.8
Aver. Horiz. Force (AVYF)	401.9	11.6	464.8	40.7
Aver.Vertical Force (AVZF)	-36.9	17.9	-55.7	16.4
Block Time (BT)	0.843	0.047	0.708	0.09
Horiz. Displ. (YDCM)	2.66	0.09	2.64	0.07
Vert. Displ. (ZDCM)	1.51	0.04	1.50	0.08
Aver. Horiz. Velocity (AVYV)	3.99	0.05	4.08	0.05
Vertical Velocity (ZV)	0.11	0.04	-0.35	0.19

Table K-3. **Subject 3. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	SD	TRACK START Mean	SD
Horiz. Impulse (YI)	317.1	3.0	320.8	5.1
Vert. Impulse (ZI)	-43.1	31.4	-65.7	6.6
Aver. Horiz. Force (AVYF)	369.6	11.9	384.9	16.5
Aver.Vertical Force (AVZF)	-49.3	33.7	-79.0	9.9
Block Time (BT)	0.935	0.064	0.896	0.025
Horiz. Displ. (YDCM)	2.52	0.05	2.83	0.07
Vert. Displ. (ZDCM)	1.51	0.05	1.57	0.03
Aver. Horiz. Velocity (AVYV)	3.79	0.06	3.96	0.04
Vertical Velocity (ZV)	-0.45	0.31	-0.63	0.13

Table K-4. **Subject 4. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	SD	TRACK START Mean	SD
Horiz. Impulse (YI)	259.2	9.9	263.4	6.3
Vert. Impulse (ZI)	-10.5	5.9	-14.5	7.7
Aver. Horiz. Force (AVYF)	315.1	3.7	379.1	16.5
Aver.Vertical Force (AVZF)	-12.7	6.6	-21.3	11.8
Block Time (BT)	0.896	0.064	0.787	0.047
Horiz. Displ. (YDCM)	2.78	0.04	2.91	0.04
Vert. Displ. (ZDCM)	1.55	0.03	1.59	0.06
Aver. Horiz. Velocity (AVYV)	3.87	0.07	3.96	0.06
Vertical Velocity (ZV)	0.303	0.128	-0.226	0.223

Table K-5. **Subject 5. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	SD	TRACK START Mean	SD
Horiz. Impulse (YI)	333.7	7.7	347.8	9.6
Vert. Impulse (ZI)	34.2	10.7	12.2	10.8
Aver. Horiz. Force (AVYF)	448.1	13.0	527.5	12.8
Aver.Vertical Force (AVZF)	46.3	15.7	19.1	16.9
Block Time (BT)	0.784	0.025	0.735	0.008
Horiz. Displ. (YDCM)	3.11	0.03	3.27	0.01
Vert. Displ. (ZDCM)	1.71	0.08	1.78	0.04
Aver. Horiz. Velocity (AVYV)	4.08	0.02	4.20	0.03
Vertical Velocity (ZV)	0.57	0.21	0.42	0.08

Table K-6. **Subject 6. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	GRAB START SD	TRACK START Mean	TRACK START SD
Horiz. Impulse (YI)	200.3	1.6	205.6	2.1
Vert. Impulse (ZI)	-9.5	3.6	-30.5	6.6
Aver. Horiz. Force (AVYF)	285.6	7.2	286.9	16.3
Aver.Vertical Force (AVZF)	-13.5	5.3	-42.1	6.2
Block Time (BT)	0.815	0.006	0.800	0.008
Horiz. Displ. (YDCM)	2.67	0.01	2.72	0.01
Vert. Displ. (ZDCM)	1.61	0.01	1.55	0.02
Aver. Horiz. Velocity (AVYV)	3.80	0.07	3.93	0.04
Vertical Velocity (ZV)	-0.03	0.06	-0.37	0.12

Table K-7. **Subject 7. Means and Standard Deviations**

Dependent Variable:	GRAB START		TRACK START	
	Mean	SD	Mean	SD
Horiz. Impulse (YI)	246.0	2.9	248.8	6.2
Vert. Impulse (ZI)	-12.7	9.1	-27.6	2.5
Aver. Horiz. Force (AVYF)	315.4	1.1	347.7	24.3
Aver.Vertical Force (AVZF)	-16.2	11.5	-38.5	0.4
Block Time (BT)	0.873	0.023	0.757	0.073
Horiz. Displ. (YDCM)	2.82	0.05	3.04	0.06
Vert. Displ. (ZDCM)	1.58	0.05	1.61	0.04
Aver. Horiz. Velocity (AVYV)	4.21	0.18	4.28	0.05
Vertical Velocity (ZV)	-0.06	0.07	-0.43	0.29

Table K-8. **Subject 8. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	GRAB START SD	TRACK START Mean	TRACK START SD
Horiz. Impulse (YI)	215.8	5.3	215.0	1.3
Vert. Impulse (ZI)	-3.7	8.6	-16.0	5.3
Aver. Horiz. Force (AVYF)	327.2	8.0	345.7	15.1
Aver.Vertical Force (AVZF)	-5.3	12.5	-26.0	9.5
Block Time (BT)	0.775	0.009	0.721	0.039
Horiz. Displ. (YDCM)	2.76	0.06	2.63	0.05
Vert. Displ. (ZDCM)	1.56	0.05	1.61	0.06
Aver. Horiz. Velocity (AVYV)	4.02	0.10	3.85	0.03
Vertical Velocity (ZV)	0.03	0.36	-0.19	0.14

Table K-9. **Subject 9. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	GRAB START SD	TRACK START Mean	TRACK START SD
Horiz. Impulse (YI)	260.6	0.5	278.9	0.9
Vert. Impulse (ZI)	-12.6	7.1	-40.3	24.0
Aver. Horiz. Force (AVYF)	382.1	14.8	423.5	6.3
Aver.Vertical Force (AVZF)	-18.7	11.1	-58.6	31.5
Block Time (BT)	0.757	0.068	0.729	0.012
Horiz. Displ. (YDCM)	2.96	0.08	3.23	0.02
Vert. Displ. (ZDCM)	1.5	0.07	1.53	0.02
Aver. Horiz. Velocity (AVYV)	4.3	0.09	4.54	0.02
Vertical Velocity (ZV)	-0.13	0.28	-0.42	0.20

Table K-10. **Subject 10. Means and Standard Deviations**

Dependent Variable:	GRAB START Mean	SD	TRACK START Mean	SD
Horiz. Impulse (YI)	267.0	5.7	261.5	7.5
Vert. Impulse (ZI)	-55.0	29.7	-44.9	19.5
Aver. Horiz. Force (AVYF)	373.0	37.0	351.0	8.6
Aver.Vertical Force (AVZF)	-68.5	38.0	-54.7	22.5
Block Time (BT)	0.812	0.029	0.812	0.042
Horiz. Displ. (YDCM)	2.79	0.02	2.96	0.07
Vert. Displ. (ZDCM)	1.57	0.04	1.67	0.04
Aver. Horiz. Velocity (AVYV)	4.12	0.05	3.83	0.26
Vertical Velocity (ZV)	0.15	0.05	-0.02	0.20

APPENDIX L

ANOVA Tables for Nine Dependent Variables

Table L-1. **Horizontal Impulse (YI)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	33310.332	3701.148	123.22	0.0000
Technique	1	117.128	117.128	3.899	0.0797
Tech. * Subj.	9	270.342	30.038		
Total	19	33697.802			

Table L-2. **Vertical Impulse (ZI)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	9273.883	1030.431	17.028	0.00013
Technique	1	927.386	927.386	15.325	0.0035
Tech. * Subj.	9	544.633	60.515		
Total	19	10745.902			

Table L-3. **Average Horizontal Force (AVYF)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	58351.853	6483.539	10.864	0.00076
Technique	1	6997.540	6997.540	11.726	0.0076
Tech. * Subj.	9	5370.984	596.776		
Total	19	70720.377			

Table L-4. **Average Vertical Force (AVZF)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	15698.773	1744.308	15.750	0.00017
Technique	1	2258.450	2258.450	20.393	0.0015
Tech. * Subj.	9	996.723	110.747		
Total	19	18953.946			

Table L-5. **Block Time (BT)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	0.048	0.005	5.0	0.01254
Technique	1	0.021	0.021	18.924	0.0018
Tech. * Subj.	9	0.010	0.001		
Total	19	0.079			

Table L-6. **Horizontal Displacement of CM (YDCM)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	0.652	0.072	8.0	0.00241
Technique	1	0.081	0.081	9.106	0.0145
Tech. * Subj.	9	0.080	0.009		
Total	19	0.813			

Table L-7. **Vertical Displacement of CM (ZDCM)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	0.082	0.009	9.0	0.00156
Technique	1	0.004	0.004	4.219	0.0702
Tech. * Subj.	9	0.010	0.001		
Total	19	0.096			

Table L-8. **Average Horizontal Velocity (AVYV)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	0.575	0.064	9.353	0.00134
Technique	1	0.014	0.014	12.390	0.0065
Tech. * Subj.	9	0.115	0.013		
Total	19	0.794			

Table L-9. **Vertical Velocity (ZV)**

Source	df	Sum Sqs	Mean Sqs	F	p
Subject	9	1.427	0.159	9.353	0.00134
Technique	1	0.212	0.212	12.390	0.0065
Tech. * Subj.	9	0.154	0.017		
Total	19	1.793			