5-1-1989

A biomechanical comparison of two relay starts in swimming

Douglas W. Gambrel
University of Nebraska at Omaha

A BIOMECHANICAL COMPARISON OF TWO RELAY STARTS IN SWIMMING

A Thesis
Presented to the
School of HPER
and the
Faculty of the Graduate College
University of Nebraska

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
University of Nebraska at Omaha

by
Douglas W. Gambrel
May 1989

THESIS ACCEPTANCE

Accepted for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree of Master of Science, University of Nebraska at Omaha.

Committee

Name	Department
Daniel Blanke	HPER
L Kay Thigpen	HPER
[illegible]	UNMC

Daniel Blanke

Chairman

January 13, 1989

Date

Acknowledgment

A tremendous amount of appreciation is extended to the members of my committee; Dr. Kay Thigpen, Dr. Morris Mellion, and especially my committee chair, Dr. Daniel Blanke. Great appreciation is also extended to Joyce Crockett for her expertise in computers.

Gratitude and love is sent to my parents Floyd and Ardelle who taught me from an early age that it is by the "Grace of God" that I can accomplish what I pursue.

This paper is dedicated to my grandfathers Herbert Thieme and Floyd Gambrel Sr. who during the final phases of my study passed away. God bless them.

Table of Contents

Table of Contents continued

List of Tables

List of Tables continued

List of Figures

List of Figures continued

List of Figures continued

CHAPTER 1

INTRODUCTION

Over the years competitive swimmers have utilized various nutrition regimens, training methods, stroke techniques, starting styles and turning techniques to improve racing performance. These activities can influence an individual's racing time by hundredths of a second; the difference between winning, losing, or breaking a world record. Competitive swimmers have used a variety of starting techniques to improve racing time. Presently, the grab and conventional starts dominate swimming competition. Recent research indicated that 10.93 meters could be covered faster by using the whip start than using the grab or swing starts (Wilson and Marino, 1983).

Research to date analyzed racing starts on an individual event basis, leaving relay event starts unresearched. The two categories in competitive swimming which utilize diving as a means of starting are individual and relay events. Both of these categories are subject to rules and regulations.

The National Collegiate Athletic Association (N.C.A.A.) (1987) established rules for men's and women's swimming and diving. These rules range from pool and equipment dimensions to rules specifically for the competitor. The equipment requirements set by the N.C.A.A. indicate that the front edge of the starting block platform must not exceed 76.20cm in height above the surface of the water and must be flush with the end of the pool. The surface of the starting platform must not be less than 50.80 by 50.80 cm and the maximum slope toward the pool not more than 10 degrees below the horizontal. Furthermore, the top must be covered with a nonskid material.

The competitor requirements are divided into individual and relay events. When competing in individual swimming events the swimmers may assume any desired position atop or aside the starting block after the official gives the command "Take your marks". When the official sees that the swimmers are completely motionless, a staring device is sounded to begin the competition.

Specific rules also govern the relay events. The freestyle and medley relay teams are comprised of four swimmers, each swimming one-fourth of the prescribed distance. The first swimmer must abide by the rules governing the start set forth for the individual events. The remaining swimmers may be in motion at the start, but must have at least one foot in contact with the starting platform at the time the preceding swimmer finishes.

When a starting stimulus is applied, the objective of a swimmer is to move off the starting block as fast as possible with maximum forward speed (Councilman, 1977). This is also the objective of the second, third, and fourth members of a relay team. For those competing in individual events and for the first member of a relay team the responsibility for a good start is primarily upon that person, assuming the starter follows the rules established by the N.C.A.A.. However, in relay events, the responsibility of a good start for the second, third, and fourth team members is shared between the incoming and outgoing swimmers. The incoming swimmers responsibility is to finish in a predicable and practiced manner which is obvious to the outgoing swimmer.

The conventional/arm swing start begins with the swimmer assuming a set position with the arms hanging down from the shoulder slightly forward of the vertical and the legs adjacent to one another at the front of the starting block **(see Figure 1)**. Upon signaling the start, the arms swing forward and upward as the swimmer's center of mass (COM) falls forward. The head is pulled downward while the arms continue to swing upward. The knees start in a bent position then extend as the arms swing forward.

Over the past two years Keith Moore (assistant swimming coach at the University of Nebraska at Lincoln) has utilized the rules governing relay competition set by the N.C.A.A. to develop a different relay start. This starting technique was coined the "step start" because it was descriptive of the actions of the lower extremities prior to take-off. As the incoming swimmer approaches the wall the swimmer atop the starting platform assumes a position in which the legs are front edge of the platform, and the rear foot positioned to the rear of the platform **(see Figure 2)**. The swimmers knees are slightly flexed, with the neck and trunk inclined in a forward and downward position. In this position the COM is placed over the rear foot. The initial movement of the swimmer is to move the COM forward. This is accomplished as the swimmer moves the rear foot forward to a position adjacent to the front foot. Once the foot has secures a firm contact with the platform, the knees, ankles, and hips extend, while the arms move forward and upward driving the COM over the surface of the water.

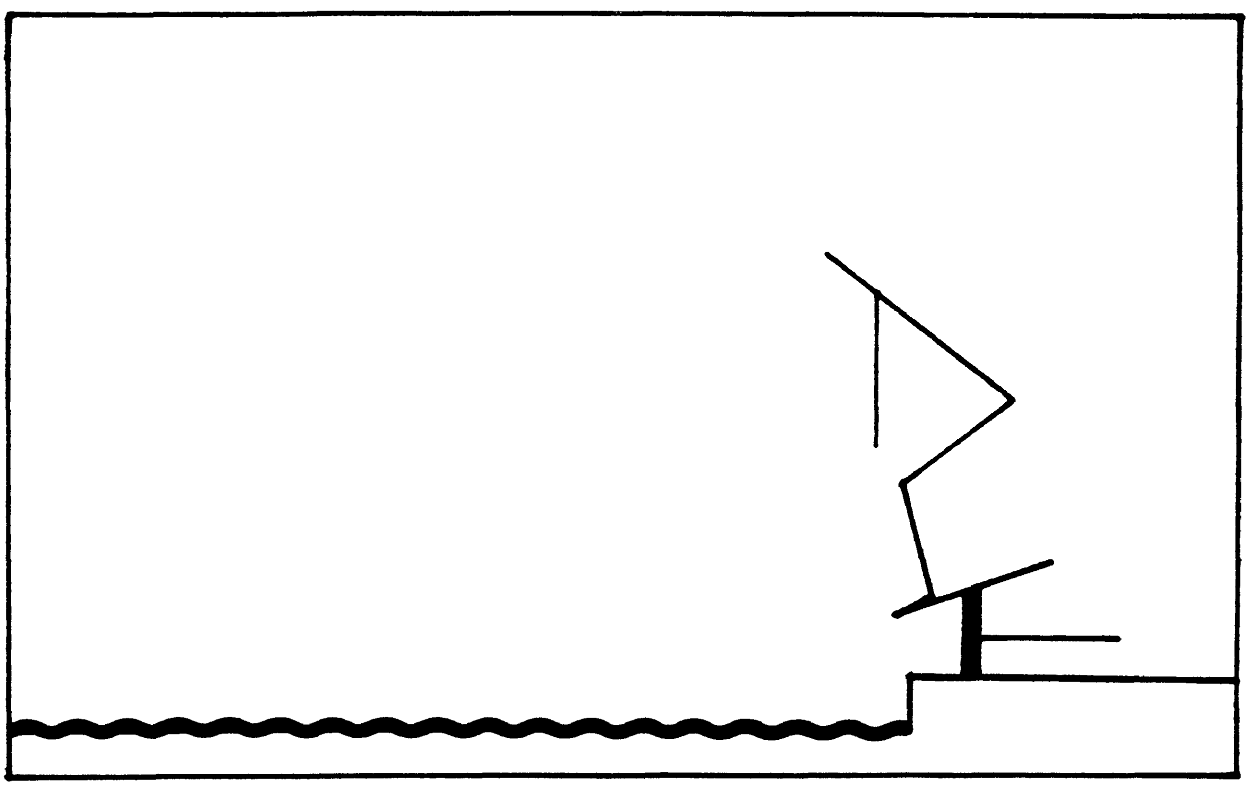

FIGURE 1 Foot Placement for the Conventional Start

The step start allows the swimmer to move the COM earlier in the start and over a larger distance. This should result in a greater velocity of the COM as the swimmers feet leave the platform.

As the competition in swimming improves, the importance of reducing the overall time of an event becomes apparent. The ability to improve a relay racing start is considered important to competitors seeking to reduce the overall relay time.

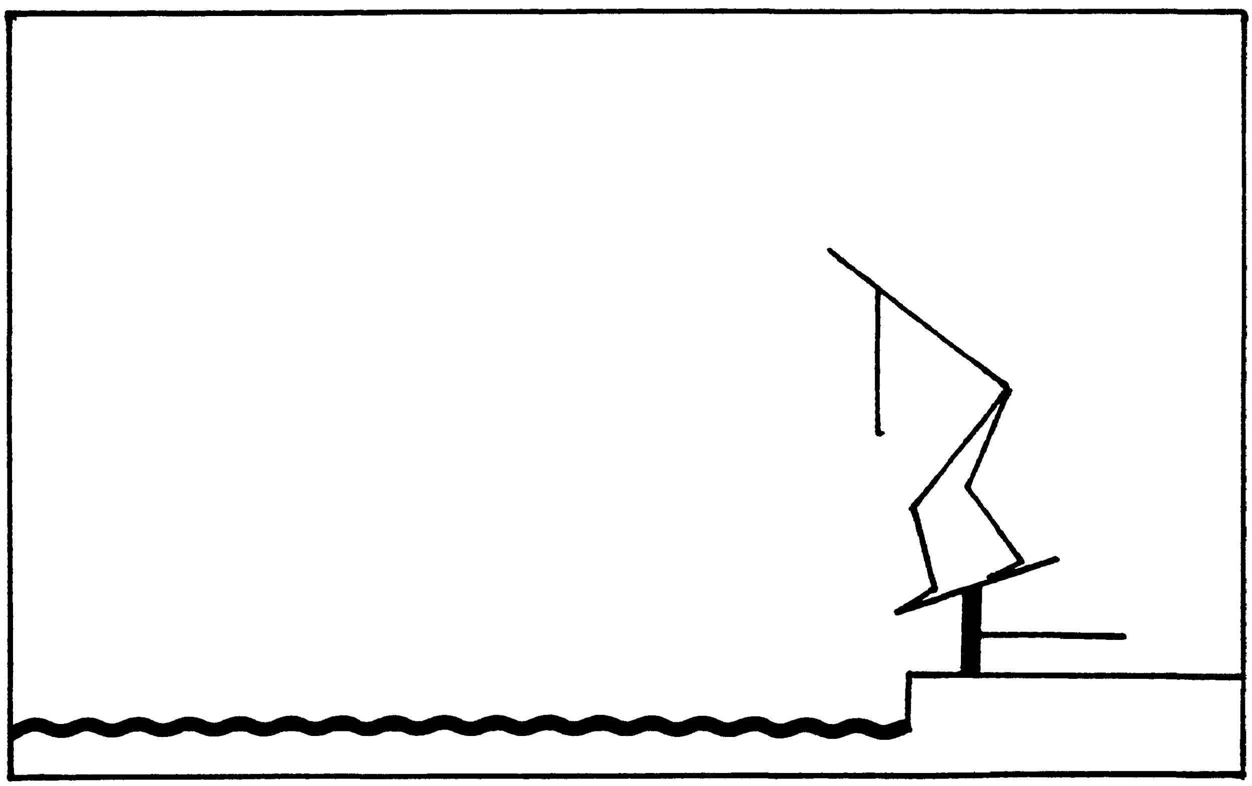

FIGURE 2 Foot Placement for the Step Start

CHAPTER 2

THE PROBLEM

Purpose

The purpose of this investigation was to identify the mechanical characteristics of the step start in relay competition and to compare this start to a traditional relay start.

Hypothesis

There will be no significant difference at the .05 level in the following parameters between the step start and the conventional relay start:

a) block time
b) flight time
c) time to 10 meters
d) flight distance
e) angle of the COM at take-off
f) height of the COM at take-off
g) height of the COM at water entry
h) horizontal velocity of the COM at take-off
i) horizontal velocity of the COM at water entry

Delimitations

Seven healthy male volunteers from the University of Nebraska at Lincoln swimming team completed a testing session consisting of eight filmed trials; four utilizing the conventional starting technique and four using the step start. Each trial consisted of a racing start and a swim to 10 meters.

Limitations

Subject cooperation and ability to follow directions may have influenced the results. Since the subjects currently use the step start in relay competition, bias could have been present. This bias should be negligible since all swimmers currently use the conventional start for their individual swimming events. To further reduce the amount of bias, a script was read to each subject prior to testing. The script:

1) informed each subject of the number and type of dive he was to perform
2) described the components of a trial
3) asked each subject to perform within the rules established by the N.C.A.A. for relay competition
4) informed each subject that the purpose of the study was to identify the mechanical parameters of both dives.

Definition of Terms

Block time - the total time from the incoming swimmer touching the wall to the time the diver's feet left the starting block.

Bulkhead - an upright partition suspended in the water separating a lane of the pool into two compartments of prescribed lengths. A bulkhead was the supporting mechanism for a touch pad.

Center of mass - the point at which the entire weight of a body may be considered concentrated so that if supported at this point the body would remain in equilibrium in any position.

Conventional start - the starting technique in which the upper extremities are involved in a backward, circular motion while the lower extremities are placed in a adjacent position prior to starting. Also called the arm swing start.

Flight distance - the horizontal distance traveled by the COM from take-off to water entry.

Flight time - time required from take-off to water entry.

Height of the COM at take-off - the vertical distance from the surface of water to the subject's COM at take-off.

Height of the COM at water entry - the vertical distance from the surface of the water to the subject's COM at water entry.

Horizontal velocity of the COM at take-off - the displacement of the subject's COM in a horizontal direction from take-off to two hundredths of a second after take-off. Velocity is recorded in meters per second.

Horizontal velocity of the COM at water entry - the displacement of the subject's COM in a horizontal direction two hundredths of a second before water entry to water entry. Velocity is recorded in meters per second.

Ready position - a desired, motionless state of the body assumed by a diver prior to the application of the starting stimulus.

Step start - the starting technique in which the upper extremities are involved in a backward, circular motion while the lower extremities are placed in a staggered position.

Take-off - the last frame in which the swimmers toes are in contact with the starting block.

Time to 10 meters - the total time required from take-off to the swimmer's fingertips touching a bulkhead, 10 meters from the front edge of the starting block. Time is measured to the nearest one thousandth of a second.

Total time - time required from when the incoming swimmer makes contact with the touch pad to when the diver makes contact the touch pad 10 meters from the front edge of the starting platform.

Touch pad - a pressure sensitive instrument used in timing.

Water entry - the frame in which the swimmers fingertips make contact with the surface of the water.

Significance of the Study

This study provides a direct comparison of selected parameters of the conventional and step starts. Coaches and swimmers can use this information to select the best start for relay competition. Since the parameters of the conventional relay start have been well documented in individual swimming events, this research will provide a means of determining these parameters in relay events. It will also provide a means of determining the same parameters for the step start.

In past years researchers have analyzed swimming starts from an individual event perspective. The focus of this study was the step start currently used by the University of Nebraska at Lincoln swimming team in relay events. Quantitative measurements of identified parameters will assist in determining how the step start compares to the conventional start currently used in swimming competition.

CHAPTER 3

REVIEW OF RELATED RESEARCH

Relay events provide some of the most exciting moments in swimming due to team competition. In relay competition the team members must maintain faster split times than the opposing teams members' in order to achieve a faster overall time. A faster split time is achieved through a faster start, swim, and/or turn time(s). As a result competitive swimmers have experimented with a number of starting techniques. These changes in starting techniques have been studied in order to verify a superior start. The following is a review of literature which documents the starting techniques used to improve times in individual events. This review will look at the traditional stance of the lower extremities, then focus on the most popular movements of the upper extremities in swimming competition. This section will also review the methods used in analyzing these different starting techniques.

A dive has been reported to begin when the starter gave the command "Take your marks". At this point a majority of swimmers moved from an erect position on top of the block to a "start", or "ready position". In the "traditional" position the swimmer usually placed his feet in a parallel stance, 6-12 inches apart with his toes curled over the front edge of the starting block. The swimmer's trunk is flexed at the hips to a point of being almost parallel to the legs with the head, neck and trunk inclined in a forward and downward position (Bloom, Hosler, & Disch, 1979; Hay, 1978).

In an attempt to provide a more efficient racing dive, LaRaue (1985) developed a new starting block. He utilized the N.C.A.A. approved starting block, accompanied by a table protruding from the posterior aspect of the block, on which a track starting block was mounted. This allowed a longer surface area for a swimmer to stagger his legs. This study found that swimmers utilizing this modified starting block were able to produce a significantly faster start when measured to 4 meters than those using the grab start. However, there are two major drawbacks to this style of dive. First, the N.C.A.A. rules limited the surface area of the starting block, and second, starting blocks do not currently provide any vertical support for the rear foot. With the exception of the research accumulated on the modified track start, most research has followed the "traditional" description of the placement of the trunk and lower extremities. Additionally, a vast amount of research has been undertaken describing the positioning and movement of the upper extremities.

The Grab Start

As early as 1976 the superiority of the grab start became evident when every competitor in the 50 meter freestyle race at the N.C.A.A. Swimming and Diving Championships used the grab start (Havriluk and Ward, 1979). The popularity of this dive initiated subsequent research.

Hay (1978) described the grab start position with the arms extended near vertically downwards and the hands gripping the front edge of the starting platform. However, in a study performed by Havriluk and Ward (1979) all three subjects utilizing the grab start, took a starting position by which the starting block was grabbed lateral to the foot placement.

Councilman (1977) reported that the grab start began with the swimmer pulling against the block through flexion of the elbows. As the swimmer lost his balance and started to fall forward, the arms started to swing forward, and the body extended as the legs drove the body forward. The leg drive continued until the ankles were extended. As the body extended, the head dropped slightly and continued to drop while water entry was made by the hands. The swimmer maintained a horizontal position while the head and shoulders were fully submerged and the body experienced a glide position under water. The first stroke was taken when the swimmer's velocity began to decrease. This start allowed the thrust provided by the arms and legs to work against the starting platform, while the action of the trunk extensors moved the swimmer as quickly as possible off the block with maximal initial velocity (Bloom, Hosler, & Disch, 1979).

The Swing Start

In 1979 the grab and conventional starts dominated swimming competition (Bloom, Hosler, & Disch, 1979; Shierman, 1979). Wilson and Marino (1983) noted that swing starts were primarily used for relay take-offs. Since a description of the grab start was established above, this section was dedicated to the "conventional" or "swing" start.

Bloom, Hosler, & Disch (1979) stated that after the swimmer assumed a "take your mark" or "set" position two variations of the arm position were possible. The first pattern appeared with the arms hanging down, the shoulder either directly perpendicular to them or slightly forward of vertical. The second body position was defined with the arms extended back in line with the upper trunk so that the hands were level or just above the hips. Maglischo and Maglischo (1967) named these dives the "straight-backswing" and the "arms-back" start, respectively.

As defined by Maglischo and Maglischo (1967), the straight-backswing start began as the swimmer assumed a set position with the hands forward, to the front of the starting block, and the fingers pointing at the bottom of the pool. At the starting signal the swimmer's hands were brought back to and slightly above the hips, then swung forward to an overhead position. The backswing of the arms produced an opposite reaction, or forward movement of the body, causing the swimmer to be thrust forward toward the water. Unlike the straight-backswing start, the arms-back starting position was set with the arms extended in line with the trunk at the end of the back-swing position. The authors felt that time would be saved if the arms were already in a backward position when the starting signal was sounded. This time saved was thought to outweigh the added force gained through the straight-backswing method.

The Circular Arm Swing Start

The swimmer assumed a set position with the arms hanging down from the shoulder slightly forward of vertical as in the conventional/swing start. Upon signaling the start, the arms were swung forward and upward as the swimmer's COM fell forward. As the swimmer moved forward, the head was pulled downward while the arms continued to swing upward. The knees bent to a greater degree than that in the set position, and the heels lifted off the block. In this curled position the body was prepared for a forward "spring", as the arms continued to swing in a circle. The legs then extend to drive the body forward as the arms swung forward. The final extension of the body was made with the arms stopping as they reached a diagonal downward position. The arms rose slightly as the head dropped between the arms and final entry was made (Councilman, 1977). Maglischo and Maglischo (1967) indicated that the circular arm swing not only produced a more forceful action by the body, but also aided the swimmer in overcoming the inertia of the backward movement of the arms.

Maglischo and Maglischo (1967) performed a study comparing three racing starts used in competitive swimming. Ten college males, swimming team members, were trained in three starting methods until there was no observable difference in the skill of executing each. The authors concluded that the speed at which the first 15 feet were traveled was significantly faster using the circular-backswing start as opposed to the straight-backswing start. Although, no significant difference was found between the straight-backswing method compared to the arms-back method of starting, and the circular-backswing start compared to the arms-back start, favor was noted for the circular-backswing.

In 1979, three Russian researchers (Zatsiorsky, Bulgakova, and Chaplinsky) performed two experiments comparing the efficiencies of four swimming start techniques, and identified the key factors that affect starting performance. The four techniques were: **1)** forward arm-swing, **2)** full arm-swing, **3)** grab, and **4)** track start. Each experiment involved 45 highly skilled male swimmers. Each swimmer received three or more daily training sessions and completed four trials of each starting technique during testing.

The first experiment revealed that the time required to cover the first 5.5 meters depended on the starting technique and not the swimming stroke performed. Further statistical analysis showed that a significant difference was the result of a poor performance in the track start. No significance was found between the other three starts. For the grab start, the magnitude of the ground reaction force was less and the duration of take-off was greater than in the traditional arm-swing starts. The ground reaction impulse was approximately equal for the forward arm swing, the full arm swing, and the grab start. The second experiment was designed to evaluate and compare selected biomechanical components in the grab start and to determine their effect on starting performance. The first stage in their study analyzed 1) support time, 2) flight time, and 3) glide time. Results indicated that total time depended most strongly on support and glide times.

The second stage of their analysis focused on the three phases of the start: support, flight, and in-water glide. The authors noted that support time should be as short as possible, while take-off conditions should provide for maximum horizontal velocity and optimal vertical velocity. In concluding the authors stated that starts involving the full arm swing, forward arm swing, or grabbing the starting block were equally efficient, while the track-start style was less efficient. It was further concluded that flight times and glide times for the grab start depended mainly on the jumping ability and size of the swimmer and that body positions and entry angle were less important.

In 1985 LaRaue compared eight variables to determine differences between the grab and the track start. Twenty female trained volunteers were subjects for this study. Of the 20 initial subjects, 19 completed a training program consisting of four one-half hour practice and videotape sessions. Eight subjects were chosen to perform five grab starts and five track starts. The author indicated from the results that the track start was faster than the grab start, although statistical information for this specific study was not available.

Ayalon, Gheluwe and Kanitz (1975) compared four styles of swimming race starts: 1) the conventional style (straight-backswing), 2) the grab start, 3) the bunch start, and 4) the track start. In the track start support of the back leg was provided. Twenty untrained male swimmers with a mean age of 22 were taught to perform the four starts. Four sessions that included 20 trials for each start and videotape feedback were used to facilitate learning. Seven subjects were chosen for the test each performing three trials. The results indicated that the swimmers using the bunch and track styles left the blocks faster than the other styles. The authors explained this was due to a low position of the body and a lack of fluctuation of the swimmers COM. The swimmer using the grab start was able to lower the COM faster than the conventional or track starts, whereas the COM for the bunch start was already low enough. The track and bunch starts were significantly faster ($p < 0.05$) than the grab start for the total time until water entry. The coordination of movement was most effective for the conventional style because the action was first started by the arms, then followed by actions at the hip, knee, and finally the ankle joints. The movements occurred simultaneously for the other starts. However, the track start had the fastest time to 5 meters.

In 1967, Erin Hanauer (Swimming and Water Polo coach at California State College at Fullerton) used photography to compare the grab start to the conventional start. One subject was filmed performing three series of both the grab and conventional start. The author's findings indicated that swimmers using the grab start assume a more compact position allowing the hands and legs or feet to push against the block. However, careful note was made indicating that short boys were able to use the grab start more to their advantage than taller boys, because shorter levers provide a greater mechanical advantage. Further research revealed the swimmers using the grab start left the starting block with a lower trajectory and a greater velocity, although statistical information was not available.

Six years later, Hanauer (1972) conducted a pilot study comparing the grab start to the conventional start this time utilizing cinematography. One subject performing one trial of each start was used. The results of this study showed identical initial movement time. However, the time from the sound of the gun to the toes leaving the block was one second faster for the grab start. In the grab start the swimmer was able to pull the body forward and down faster than gravity alone could accomplish. The swimmer hit the water first using the grab start, but was 8 1/2 inches closer to the starting block than when using the conventional start. The conventional start covered the time to water with a faster velocity. The slight advantage in distance and velocity favoring the conventional start was largely reduced by the speed advantage of the grab start. The speed advantage was gained by the time the upper body was parallel to the surface of the water. The angle of entry was identical for both starts, approximately 15 degrees. He suggested a limitation of this project being that the grab start could have been a better dive for this particular swimmer.

Bloom, Hosler, and Disch (1979) directed a study in which differences in flight, reaction and movement time were analyzed for the grab and conventional starts. Thirty untrained females ranging in age from 19 to 26 were randomly assigned to either the grab or conventional start. Ten training sessions were conducted for both groups. The results of this study suggested that the grab start produced faster times on each of the dependent measures. However, examination of both univariate and step down F's indicated that the only significant difference occurred with movement time. A possible explanation for the difference in movement times was the use of the arms in pushing off the blocks and a more tensed position in the grab start. Furthermore, the authors suggested that it appeared as if the swimmer was allowed a more ready position with the grab start.

In 1979 Havriluk and Ward designed a study to analyze three college swimmers. Each subject performed one trial as they would in competition. The authors suggested that the subject with the superior dive kept the COM farthest forward in the starting position, established the smallest radius of rotation (distance between the COM and the forward, edge of the starting block) and had the fastest resultant take-off velocity and response time.

A recent study by Guimaraes and Hay (1985) analyzed the mechanics of the hands-between-the-feet grab start technique. The subjects involved were 24 trained high school students with an average of 6 years in competitive swimming. Each subject performed four trials, each trial consisting of a grab start and glide. Three variables studied revealed that when performing the grab start technique with the hands-between-the-feet, swimmers should move their COM faster in the forward direction while their feet were in contact with the starting block and thus maximize the force exerted by the hands against the front edge of the starting block in the backward and down direction.

Wilson and Marino (1983) designed a study analyzing selective mechanical aspects of the whip, grab, and swing starts. Twelve highly skilled males and females were randomly selected and assigned to perform one of the three starts they preferred. A total of fourteen variables revealed that the techniques of take-off and water entry can be manipulated to produce a faster start. The authors concluded that due to a higher angle of body lean at takeoff, the whip start required less time on the starting block than the grab start and the swing start. The grab start technique produced horizontal take-off velocities similar to the swing start but in a significantly shorter period of time. It was also shown that male subjects take off with a higher horizontal velocity and travel farther before entry than female subjects using similar starting techniques. A higher angle of body lean coupled with greater hip flexion prior to entry facilitated a more effective hole entry. The hole entry produced a significantly faster time to cover a significantly longer distance in the water than the flat entry. The authors also concluded that the use of the whip start allowed a swimmer to cover a distance of 10.93 meters significantly faster than swimmers using the grab start or swing start.

Analysis Methods

Approaches to swimming start analysis have followed many different routes because of the availability and expense of measuring devices. The literature reviewed indicated that researchers have most often opted to use photography, or high speed cinematography.

In 1967 Hanauer used a Graph-check camera, set to operate at 1.6 seconds. This method of photography produced a Polaroid film consisting of eight separate frames, each representing 1/1000 of a second. Other researchers have used video-taping to provide feedback in starting techniques (Bloom et. al., 1979; Newble, 1982). However the majority of the research utilized high speed cinematography. Filming methods used to investigate starting techniques have measured a number of parameters which included: movement time, flight time, dive time, angle of projection, angle of body lean at take-off, angle of trunk above horizontal, flight distance, position of the COM in the ready position, and horizontal velocity of the COM at take-off and entry.

Guimaraes and Hay (1985) described a method utilizing a Colorado Timing System, a 16 millimeter motion picture camera and a force measuring device. The Colorado Timing System was used to start and time the subjects up to a nine meter distance. The camera was mounted on a tripod with the frontal plane of the lens set parallel to the plane of motion. Placement of the camera was set at a distance of 16 meters from the starting block, and operated at 100 frames per second. The force measuring device consisted of a supported steel bar (diameter = 0.025 meters) mounted on the front edge of the starting block. This device measured forces in the horizontal and vertical direction. In 1979, Sheirman measured force via a Kisler Force Platform. This device was capable of obtaining three force components, the horizontal side-to-side component, the horizontal fore and aft component, and the vertical component.

Other timing mechanisms have contributed to diving research. Michaels (1982) measured starting efficiency using a manual stop watch. Van Slooten (1973), and Maglischo and Maglischo (1967) used a Dekan automatic performance analyzer to measure movement to .001 of a second. A more complicated timing device used by Tuttle, Morehouse and Armbruster (1939) consisted of a stimulus unit, a response unit, and a recording unit.

Data reduction techniques were also varied. Van Slooten (1973) used a method of projecting the processed film onto a wall with a Lafayette projector and then plotted reference points on graph paper. Havriluk and Ward (1979) projected the processed film onto a plexiglass screen. Guimaraes and Hay (1985) analyzed film using a more elaborate method via a Vanguard Motion Analyzer.

Summary

Over the years competitive swimmers have utilized various body positions in performing racing dives. In past years the grab and conventional starts have dominated swimming competition. However, recent research indicated that the whip start allowed a swimmer to cover a distance of 10.93 meters faster. Changes in body position altered the parameters necessary in executing a swimming dive. These changes in body positions affected block time, flight time, and water time.

Fluctuations in the speed and changes in the location of the COM as well as the ability of the diver to assume a low, compact body position contributed to the block time. The use of the hands in the grab start allowed a swimmer to pull the body forward and downward faster than gravity alone could accomplish and contributed to the amount of force applied against the block. The whip start required less time on the starting block than the grab or swing starts due to a higher angle of body lean at take-off. A successful swimming start was directly related to the ability of the swimmer to keep his COM forward in the starting position, to generate the fastest resultant take-off velocity and to generate the smallest or largest response time.

Diving performance has been studied utilizing cinematography. A LoCam camera was generally used with the lens of the camera placed parallel to the plane of motion and set to operate at 100 frames per second. The processed film was then digitized for X and Y coordinates to calculate the various performance parameters.

CHAPTER 4

METHODS

Subject Definition

The subjects for this study were seven college age males with at least eight years of competitive swimming experience. All were members of the University of Nebraska at Lincoln swimming team. All of the swimmers had previous experience with both conventional and step starts and therefore no training period was utilized. All subjects had been taught the step start by Keith Moore (assistant coach for the Nebraska swimming team) and were currently using this dive in relay competition. On the day of testing each subject was free of any physical disability or ailment that could cause an impedance to that subject's ability to perform. Each subject provided informed consent in accordance with the procedures required by the Institutional Review Board of the University of Nebraska.

Experimental Procedure

Subjects were scheduled for one testing session. The day of testing each subject was weighed and had his height measured. In order to control the effect of learning and fatigue in a testing session each subject was randomly assigned to one of two starting orders. The assignment was made in accordance with the sampling without replacement procedure described by Keppel (1973). Prior to testing, each subject was read a script of specific instructions. The script content read as follows:

> The purpose of this study is to evaluate the mechanics of two different relay starts. Each of you will be asked to perform eight relay starts, four using the traditional start and four using the step start. You will follow the same rules set by the N.C.A.A. for relay competition, keeping at least one foot on the starting block until the prior swimmer has touched the wall. Once you have completed a dive you will swim with maximum effort to a touch pad placed on the front of the bulkhead positioned 10 meters down the pool lane. This procedure will be filmed by a camera to your left. In addition you will be asked to perform each dive to the best of your ability as if you were competing. Thank you, for your participation in this study.

After listening to the script, the swimmers were asked to warmup as they would prior to any competition. Since competitive swimming apparel consists of small racing suits, instruction to appropriate clothing was unnecessary.

A trial consisted of a swimmer in the water swimming at full speed to the end of the pool at which time a subject from atop the starting block dove and swam (approximately three arms strokes) to a bulkhead. Subjects were randomly divided in two groups. One group consisted of four swimmers and the other consisted of three. Each subject performed eight starts; four demonstrating the step start and four demonstrating the conventional start. Each subject was instructed to complete all four trials of the dive chosen in the randomization before performing the other dive. Subjects were to rotate within their group, first from the pool deck to the starting block, then to water. All testing was performed in the natatorium at the University of Nebraska at Lincoln. Because of the humidity in the natatorium, the submersion of each subject in water, and the unavailability of a suitable material, anatomical landmarks were not marked on the subject. However, the following 17 anatomical landmarks were identified on film:

1) right tip of foot
2) right ankle
3) right knee
4) right hip
5) right shoulder
6) top of head
7) right elbow
8) right wrist
9) right tip of hand
10) left tip of foot
11) left ankle
12) left knee
13) left hip
14) left shoulder
15) left elbow
16) left wrist

17) left tip of hand

Instrumentation

High speed cinematography was used to determine the swimmer's movements. A LoCam, model 51, 16mm camera with a 25mm F1.4 lens was mounted on a tripod and leveled. The camera contained an internal timing light generator set to mark the edge of the film at 100Hz. The camera was located at a distance of 16.1 meters from the center of the diving lane. At this distance the start of the dive and entry of the fingertips into the water was completely within the field of view of the camera. The camera was directly perpendicular to the starting lane at a point halfway between take-off and water entry. The camera's position remained consistent for all trials. The camera was loaded with Kodak 7277 4x reversal black and white film and was set to operate at 100 frames per second. A trial marker and meter reference were also included in the camera's field of view. Lighting consisted of the natatorium ceiling lights as well as four high intensity Pallite VIII lamps with an output of 2400 watts each **(see Figure 3)**.

The processed film was displayed on a Lafayette Data Viewer rear projection system. Frame rate was calculated by counting the marks displayed on the edge of the film from frame 0 to frame 50. Since fifty marks were counted the frame

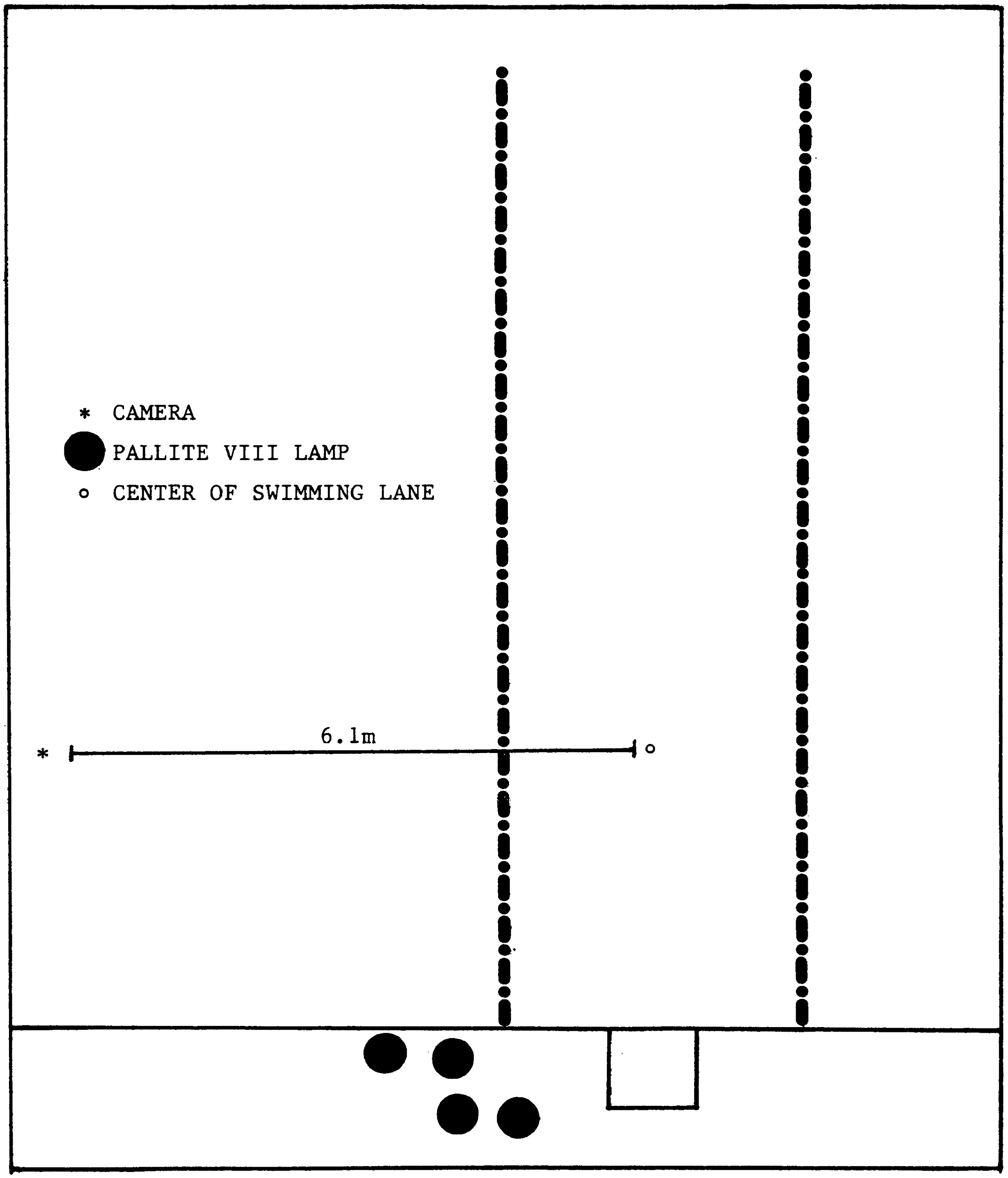

FIGURE 3 Floor Plan of the Natatorium

rate was determined to be one hundred frames per second using the formula:

$$\textbf{frame rate} = \frac{\textbf{\# frames elapsed}}{\textbf{\# time elapsed}}$$

The film was first viewed at 24 frames per second. The film was then digitized for X and Y coordinates every two hundredths of a second beginning with the fortieth frame prior to take-off and ending at water entry. A scale factor was calculated by measuring the meter reference in the field of view of the camera. The scale factor for this study was 0.0619578. The following equation represents the scale factor:

$$\textbf{Scale Factor} = \frac{\textbf{one meter}}{\textbf{measured length of meter on the film (in digitizer units)}}$$

Parameters

The following parameters were measured. In examination of a start in swimming the most common measure of block time is the time from the starting stimulus to the time the diver's feet leave the starting block. However, this definition of block time is invalid for the second, third, and fourth members of a relay team because the starting stimulus for these members is purely visual, being determined by the pace of the incoming swimmer.

Block time was defined as the time from the incoming swimmer touching the wall to the time the diver's feet left the starting block. This time was measured using two touch pads, one on the inside wall of the swimming pool and the other atop the starting block. Both pads were attached to a timer. As the swimmer in the water touched the pad a timer was started. When the diver's feet left the pad atop the block, the timer was stopped. Time was measured to the nearest one hundredth of a second.

Center of Mass was determined by entering X, Y coordinates of the 17 identified anatomical landmarks into a computer in a specific order. A computer program used data available on weights and lengths of body segments to calculate the COM.

Flight time was the time elapsed from the frame in which the diver's feet left the platform to when his fingertips made water entry. Time was calculated by counting the number of frames which elapsed during the movement divided by the frame rate.

Time to 10 meters was the total time required from the take-off to the swimmer's fingertips touching a touchpad secured on a bulkhead 10 meters from the front edge of the starting block. This time was established using three touch pads, and a timer. One touch pad was mounted on the inside wall of the pool and programed to start when the incoming swimmer touched the pad. The second touchpad was mounted was mounted on the front edge of a bulkhead positioned 10 meters from the front edge of the starting platform and programed to stop the timer when touched by the diver. Time to 10 meters was calculated by subtracting the block time from the total time. Time was measured to the nearest one hundredth of a second.

Flight distance was measured as the horizontal distance the COM moved from the frame of take-off to the frame of water at entry. Flight distance was the length measured on the screen multiplied by the scale factor.

Angle of the COM at take-off was calculated by plotting the position of the COM at take-off and two hundredths of a second after take-off. The angle that resulted from the line connecting these two points and a horizontal line is the angle of the COM at take-off in degrees.

Height of the COM at take-off was determined by measuring the vertical distance from the surface of the water to the COM at take-off. Values were then multiplied by the scale factor to determine the height of the COM at take-off.

Height of the COM at water entry was determined by measuring the vertical distance from the surface of the water to the COM at water entry. Values were then multiplied by the scale factor to determine the height of the COM at water entry.

Horizontal velocity of the COM at take-off was determined by measuring the horizontal distance the COM traveled from take-off to two hundredths of a second after take-off. This value was then divided by the time that elapsed during the movement. Actual distance was then calculated by multiplying the length measured on the screen by the scale factor as previously described. Time was calculated by counting the applicable frames divided by the frame rate. Velocity was measured in meters per second.

Horizontal velocity of the COM at entry was the distance the COM traveled two hundredths of a second from water entry to water entry. This value was then divided by the time that elapsed during this action. Actual distance was the measured length multiplied by the scale factor. COM and time were calculated as previously described. Velocity was measured in meters per second.

Statistical Treatment

Individual parameter values were calculated utilizing the mean of three of the four trials for each subject. In situations where all four trials were readable the three trials demonstrating values closest to the mean time to 10 meters were chosen. The mean and standard deviation for all three trials for each subject was calculated for all parameters. The mean and standard deviation for all subjects was then determined for each parameter. Path of the COM and horizontal velocities were plotted for each subject. A sliding or running average smoothing program was used to average the path of the COM and the horizontal velocities. A width of 7 was used to smooth the path of the COM and a width of 11 was used to smooth the horizontal velocities. For each parameter, a dependent t-test was used to compare mean scores for the step start and the conventional start. All comparisons were evaluated at the .05 level of significance.

Test-retest reliability coefficients were calculated for seven of the parameters to determine investigator reliability. A reliability coefficient of 0.985 for the height of the COM at take-off and 0.960 for the height of the COM at water entry were calculated. Reliability for the horizontal velocity of the COM at take-off and water entry were calculated to be 0.943 and 0.925, respectively. Reliability for the angle of take-off for the COM was 0.967. Reliability for flight time and flight distance were 1.00 and 0.962, respectively. The investigator performed all measurements.

CHAPTER 5

RESULTS

Basic descriptive characteristics of each swimmer are presented in **Table I.** **Table II** contains the group means, standard deviations, and t-test values for all the parameters of the step and conventional starts. No statistically significant differences ($p > .05$) were found for any of the parameters. A comparison of the means of these group parameters indicate that the swimmers using the step start had the longest block times and were also able to accumulate the largest horizontal velocities. No differences were found between group means of the height of the COM at take-off and water entry. Although the angle at take-off of the COM for the step and conventional start indicated no significant difference, the standard deviation of the step start was larger than that of the conventional start. Group means indicated that time to 10 meters could be covered faster using the step start than using the conventional start. Group means further reveal that a larger flight distance was covered using the step start than the conventional start. However the flight time for the group means remained the same.

Although no significant difference was found between block times for the step (0.16 $\pm$ 0.08 sec.) and conventional (0.13 $\pm$ 0.06 sec.) starts, times were similar to those

TABLE I
Basic Descriptive Characteristics of Each Subject

Subject	Height (cm)	Mass (kg)
1	27.75	70.91
2	28.35	71.84
3	29.03	71.82
4	30.12	89.54
5	29.26	88.64
6	30.31	85.91
7	28.15	83.64

TABLE II
Group Means, Standard Deviations, and *t*-ratios for Each Selected Parameter

Parameters	Step X ± SD N = 7	Conventional X ± SD N = 7	*t**
Block Time	0.16 ± 0.08	0.13 ± 0.06	1.691
Time to 10 meters (sec.)	2.96 ± 0.16	3.03 ± 0.15	-1.699
Height of COM at Take-off (meters)	1.40 ± 0.07	1.39 ± 0.05	1.268
Height of COM at Water Entry (meters)	0.76 ± 0.06	0.76 ± 0.06	.370
Horizontal Velocity of COM at Take-off (m/s)	4.57 ± 0.28	3.56 ± 0.15	.107
Horizontal Velocity of COM at Water Entry (m/s)	4.38 ± 0.19	4.30 ± 0.07	1.108
Flight Time (sec.)	0.42 ± 0.05	0.42 ± 0.04	.190
Flight Distance (meters)	1.81 ± 0.19	1.78 ± 0.18	.835
Angle at Take-off (degrees)	55.93 ± 1.43	55.81 ± 0.81	.163

***DF = 6**
****p > 0.05**

reported in the literature (0.18 ± 0.04 sec.) for the grab start (Havriluk and Ward, 1979). Height of the COM at water entry for both the step and conventional starts was 0.76 ± 0.06 meters. These values were somewhat larger than the values 0.59 ± 0.08 meters) found by Guimaraes and Hay (1985) in a study involving twenty-four high school students demonstrating the grab start. Subject means and standard deviations for each parameter of the step and conventional starts are presented in **Tables III-XI** in **Appendix A.**

Figure 4 represents the path of the COM from take-off to water entry for all seven subjects utilizing the step start. **Figure 5** represents the path of the COM from take-off to water entry for all seven subjects using the conventional start. No significant differences were found between the height of the COM at take-off and water entry. However, the path of the COM for subjects using the step start varied to a greater extent than the path of the COM for the subjects using the conventional start.

Although small differences were found between the Horizontal velocity for the step start (4.57 ± 0.28 m/sec.) and the conventional start (3.56 ± 0.15 m/sec.) both scores were similar (4.33 ± 0.61 m/sec.) to those found in research of the grab start by Havriluk and Ward (1979). **Figures 6** and **7** illustrate the horizontal velocities from take-off to water entry for each subject using the step and conventional start, respectively. It would appear that the horizontal velocities

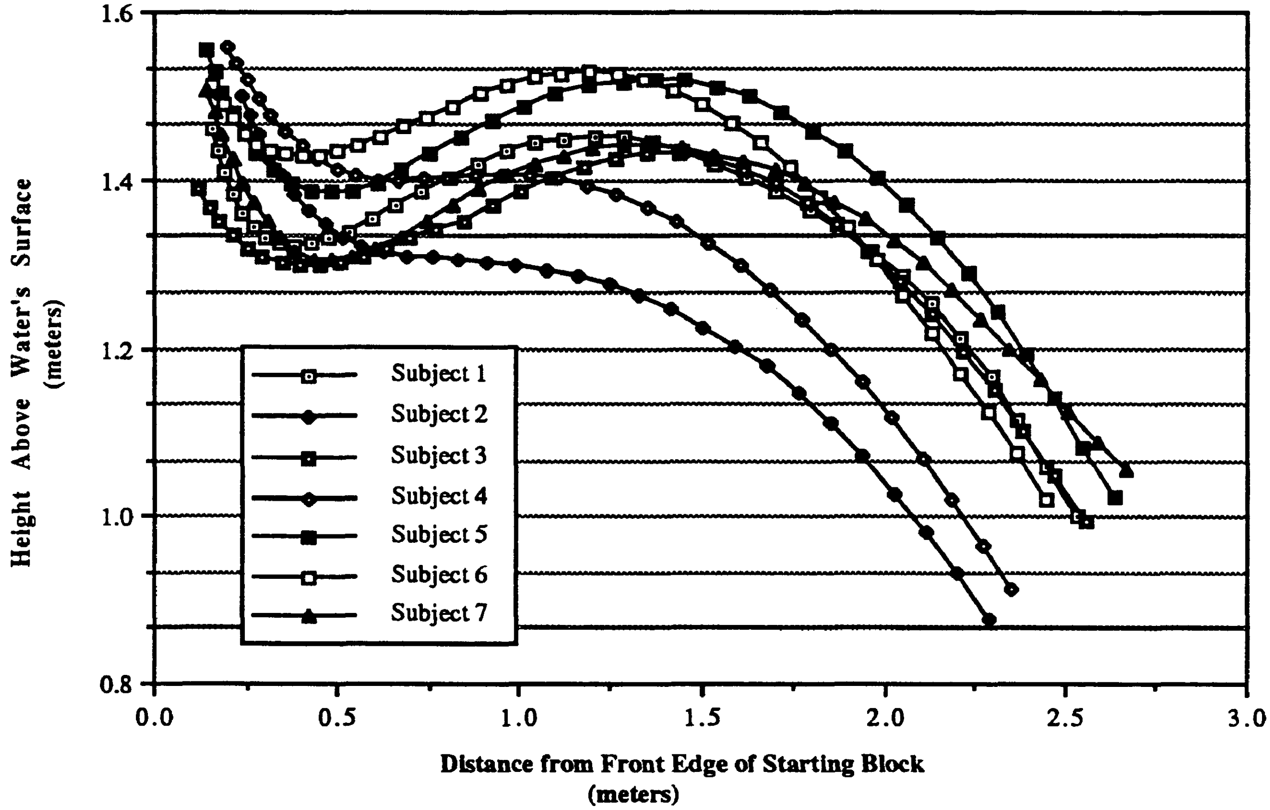

Figure 4. Path of the COM for Each Subject Using Step Start

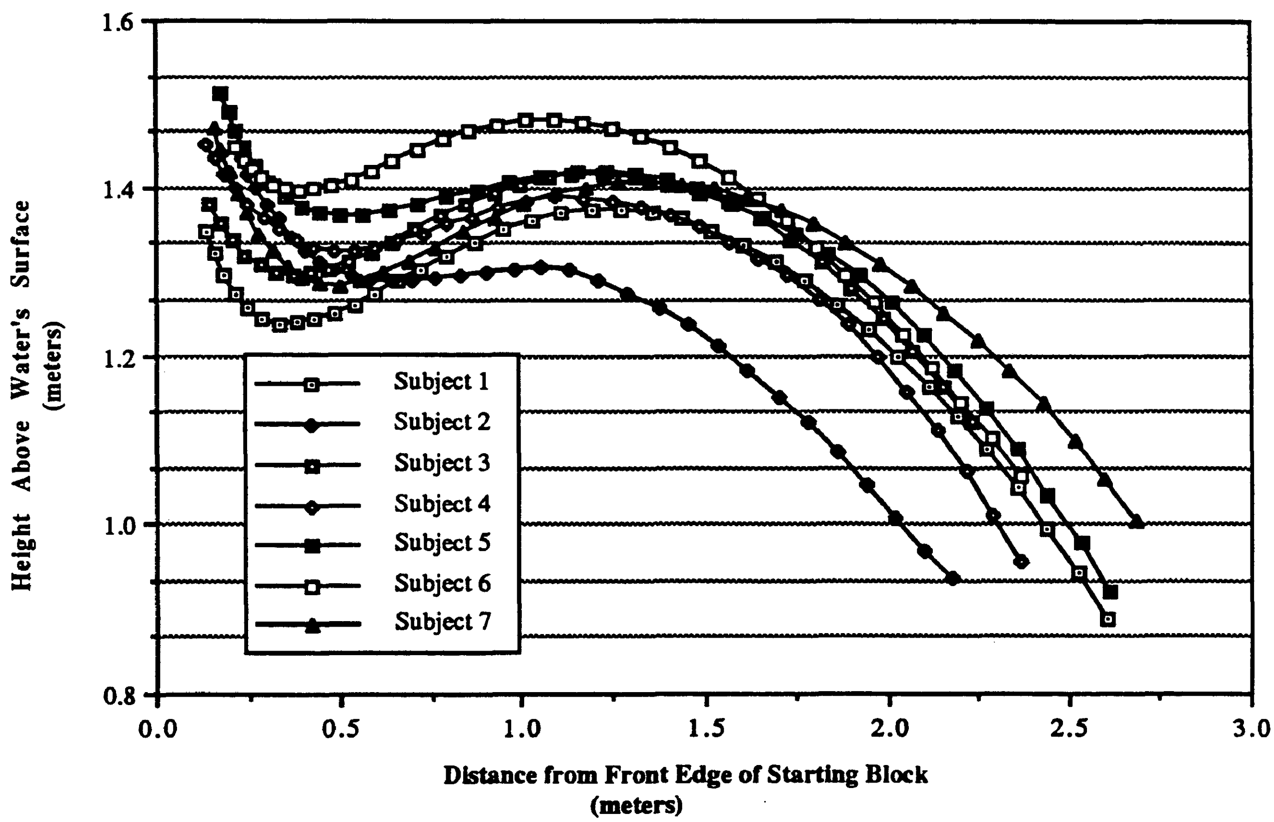

Figure 5. Path of the COM for Each Subject Using Conventional Start

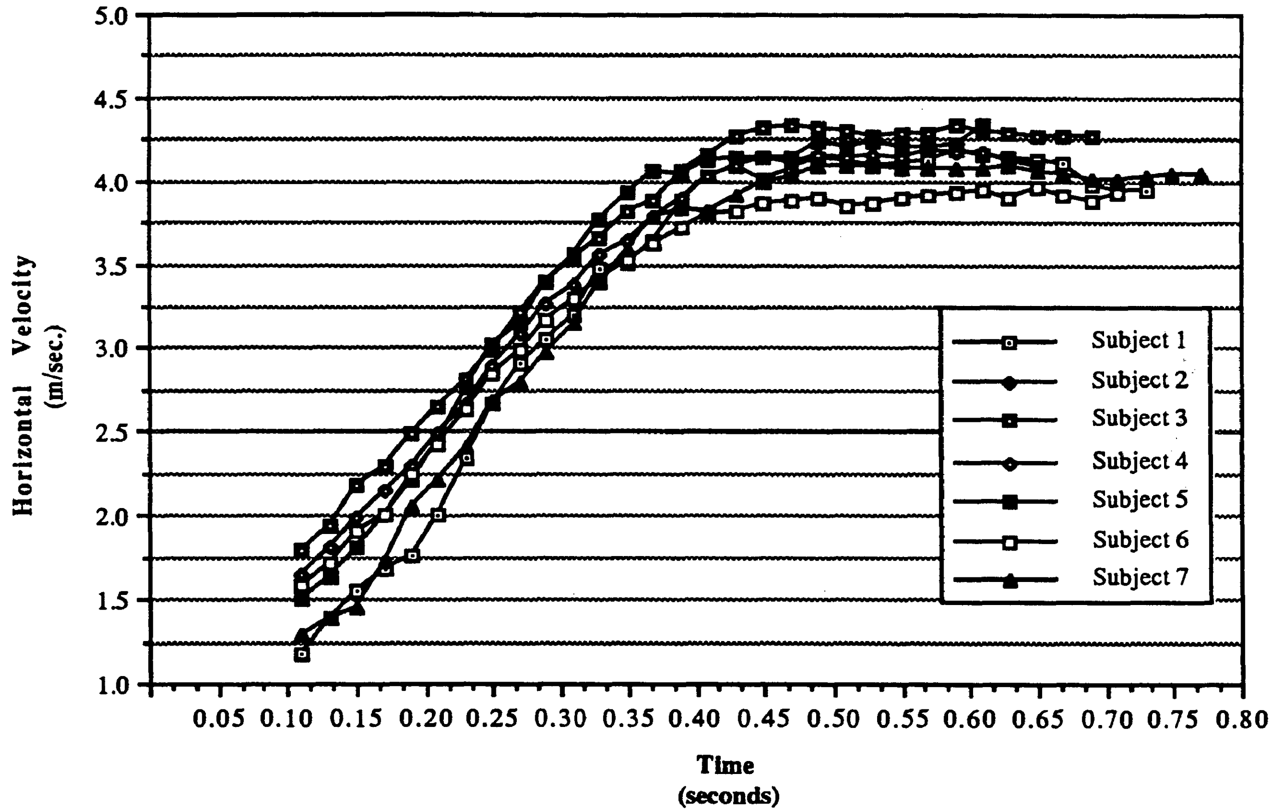

Figure 6. Horizontal Velocity of the COM for Each Subject Using Step Start

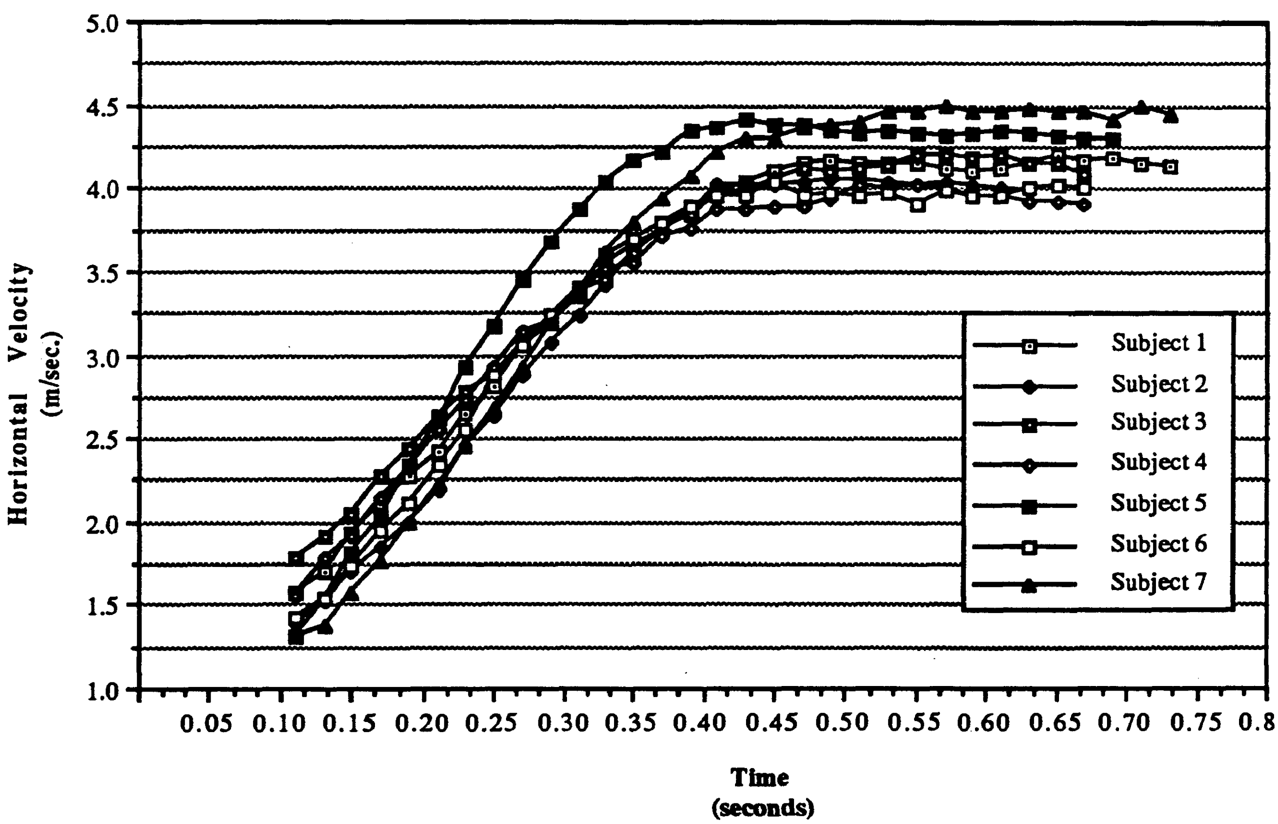

Figure 7. Horizontal Velocity of the COM for Each Subject Using Conventional Start

of the COM for the subjects using the conventional start varied to a greater extent than the horizontal velocities of the COM for the subjects using the step start.

No difference was found between the flight times for the step start (0.42 ± 0.05 sec.) and the conventional start (0.42 ± 0.07 sec.). However, flight times were found to be somewhat slower than flight times found in the whip (0.34 ± 0.03 sec.), grab (0.30 ± 0.04), and swing (0.31 ± 0.06) among Canadian Olympic male swimmers (Wilson and Marino, 1983).

Figures 8-14 in **Appendix A** illustrate the path of the COM using both the step and conventional starts for each subject. All seven subjects when using the step start began with their COM higher than when using the conventional start. Four of these subjects continued to maintain a higher COM throughout the dive. Of the four subjects that maintained a higher COM throughout the entire dive, only one was able to project his COM further using the step start. Three subjects demonstrated a lower COM at two different locations in the path. One subject demonstrated a lower COM prior to take-off and the other two subjects from take-off to water entry. The two subjects that maintained a higher COM from take-off to water entry also projected their COM further from the starting block.

Figures 15-21 in **Appendix A** illustrate the horizontal velocities of the COM for each subject using the step and conventional start. Six of the seven subjects using the conventional start were able to maintain larger horizontal velocities of the COM from take-off to water entry. Whereas, only one of the seven subjects using the step start was able to maintain a somewhat larger horizontal velocity of the COM from take-off to water entry. However, this same subject was able to produce a longer flight time using the conventional start.

CHAPTER 6

DISCUSSION

Research on racing starts in swimming has been limited to individual events, while research in the area of relay events for the second, third, and fourth diver has been unresearched. Previous studies on racing starts have focused on traditional starting methods with the swimmer assuming a desired, motionless position atop the starting block prior to the official starting the race (Bloom, Hosler, & Disch, 1978; Guimaraes, and Hay, 1985; Havriluk, and Ward, 1979; Wilson, and Marino, 1983). The present study resulted from a need for quantitative measures in relay starts to be used as a baseline for comparisons and further study.

No significant differences were found between any of the parameters. However, mean times indicated that the longer the subject's block time, the greater the horizontal velocity, and the longer the flight distances. In addition, no significant differences were found between the means of the angle at take-off of the COM. Therefore, it is not surprising that the mean flight distance between the step and conventional starts also displayed no significant difference. The slightly longer flight distance achieved by the subjects demonstrating the step start was felt to have been influenced by the flight path since no difference in the take-off angle of the COM existed.

Plots of the horizontal velocities of the COM of each subject for the step and conventional starts illustrated an increase in velocity until take-off and then a slight decrease until water entry. Comparing the step with the conventional start showed similar paths for all seven subjects.

The path of the COM prior to take-off exhibited large differences in the height of the subject's COM until take-off. This is not surprising since all seven subjects exhibited a higher body position atop the starting block prior to take-off. However, both the height of the COM at take-off and water entry revealed no significant difference between dives. All seven subjects showed consistent flight paths for the COM when demonstrating both the step and conventional starts. However, the path of the COM for subjects using the step start varied to a greater extend than the path of the COM for the subjects using the conventional start. This fluctuation in the path of the COM when using the step start is felt to be a direct result of the subjects moving their COM over a larger distance atop the starting block during the stepping phase of the rear foot to a position adjacent to the front foot.

Time to 10 meters also showed no significant differences between starts. Time to 10 meters is not only dependent upon horizontal velocity, but also upon water time. Water time is determined by the distance the subject travels in the water and the velocity in the water.

This research indicates that the step start shows no noticeable superiority to the conventional start. However, it is the opinion of this author that the step start seems to be at least as good as the "traditional" start. This is quite an accomplishment since the step start has been recently developed and the conventional start has been used for some time.

CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATION

Summary

The purpose of this investigation was to evaluate the mechanical characteristics of the step start in relay competition and to compare this start to a conventional relay start. Seven college age males, all members of the University of Nebraska at Lincoln swimming team, were subjects for this study. All subjects were free of any physical disability or ailment that might have caused any impaired performance.

All subjects completed one testing session consisting of four filmed trials each of the step start and the conventional start. High speed cinematography (100 frames/second) was used to film the subjects from a side view. The processed film was analyzed for nine parameters using a Lafayette projection system, a Numonics digitizer, and the University of Nebraska at Omaha's VAX computer system.

The results were summarized as follows:

1. No significant difference was found between the starts for block time. The values were within normal ranges from other studies (Havriluk and Ward, 1979).
2. No significant difference was found between the starts for height of the COM at take-off or at water entry.
3. No significant difference was found between the starts

for either horizontal velocity at take-off or at water entry. Values of this parameter agreed with values presented for horizontal velocities at take-off and water entry from other studies involving college age swimmers (Havriluk and Ward, 1979).

4. No significant difference was found between starts for flight time or flight distance.
5. No significant difference was found between starts for the angle at take-off.

Conclusions

For the sample of subjects in this study, the following conclusions were made:

1. The data indicated that the step and conventional starts for relay competition are very similar in their performance parameters.
2. From the results of this study the step start is as good as the conventional start for relay competition.

Recommendations for Further Study

From the findings of this study several recommendations were made concerning further research on comparisons of relay dives for competition.

1. A similar cinematographic analysis should be conducted during actual relay competition.
2. Future studies should incorporate additional performance

parameters to be examined and compared for the step and conventional starts.

3. A similar study with noncompetative swimmers should be undertaken for performance parameter comparisons.

REFERENCES

Ayalon, A., VanGheluwe,B., & Fanitz, M. A comparison of four styles of racing start in swimming. In L. Lewillie and J.Clarys (Eds.), Swimming II. International Series on Sports Sciences, Baltimore: University Park Press, 1975, 233-240.

Bloom, J., Hosler, W., & Disch, J. Differences in flight reaction & movement time for the grab & conventional starts. Swimming Technique, 1978, 15, 34-36.

Counsilman, James E. Competitive Swimming Manual for Coaches and Swimmers. Bloomington: Counsilman Co., Inc, 1977.

Guimaraes, A. and Hay, J.G. A mechanical analysis of the grab starting technique in swimming. International Journal of Sports Biomechanics, 1985, 1, 25-35.

Hanauer, E.S. The grab start. Swimming World and Junior Swimmer, 1967, 8, 4-5,42.

Hanauer, E.S. Grab start: faster than conventional start. Swimming World and Junior Swimmer, 1972, 13, 8-9, 54-55.

Havriluk, R., and Ward T. A cinematographic analysis of three grab starts. Swimming Technique, 1979, 16, 50-52.

Hay, J.G. Starts. The Biomechanics of Sports Techniques. New Jersy: Prentice-Hall, Inc., 1978, 373.

Keppel, G. Design and Analysis: A Researchers Handbook, New Jersey: Prentice-Hall Inc., 1973, 27.

LaRue, R.J. Future start. Swimming Technique, 1985, 21, 30-32.

National Collegiate Athletic Association. 1987. 1987 N.C.A.A. Swimming & Diving. Mission, Kansas: National Collegiate Athletic Association.

Newble, D. A method of analyzing starts and turns in competitive swimming. The Australian Journal of Sport Sciences, 1982, 2, 11-13.

Maglischo C.W., and Maglischo, E. Comparison of three racing starts used in competitive swimming. Research Quarterly, 1967, 39, 604-609.

Michaels, R.A. Basic measurement techniques in start and turn analysis. Scholastic Coach, 1982, 51, 18,76.

Shierman, G. The grab and conventional swimming starts: a force analysis. Journal of Sport Medicine and Physical Fitness, 1979, 19 171-180.

Tuttle, W.W., Morehouse, L.E., & Armbruster, D. Two studies in swimming starts. Research Quarterly, 1939, 10, 89-98.

Van Slooten, P.H. An analysis of two forward swim starts using cinematography. Swimming Technique, 1973, 10, 85-88.

Wilson, Don S., and Marino Wayne G. Kinematic Analysis of Three Starts. Swimming Technique, 1983, 19, 30-34.

Zatsiorsky, V.M., Bulgakova, N.Zh., & Chaplinsky, N.M. Biomechanical analysis of starting techniques in swimming. J. Terauds and E.E. Bengingfield (Eds.), *Swimming III. International Series on Sports Sciences*, Baltimore: University Park Press, 1979, 199-206.

APPENDIX A

TABLE III
Means and Standard Deviations of Block Times for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	0.06 ± 0.08 *	0.05 ± 0.01 *
2	0.08 ± 0.03	0.11 ± 0.06
3	0.11 ± 0.03	0.12 ± 0.13
4	0.20 ± 0.01	0.23 ± 0.06
5	0.12 ± 0.07	0.09 ± 0.10
6	0.24 ± 0.03	0.16 ± 0.07
7	0.23 ± 0.10	0.13 ± 0.04

* Seconds

TABLE IV
Means and Standard Deviations of Time to 10 Meters for Each Subject

Subject	**Step** **X ± SD** N = 3	**Conventional** **X ± SD** N = 3
1	2.84 ± 0.07 *	3.10 ± 0.01 *
2	2.98 ± 0.10	3.11 ± 0.19
3	3.08 ± 0.11	3.09 ± 0.03
4	3.13 ± 0.03	3.09 ± 0.06
5	2.69 ± 0.16	2.72 ± 0.04
6	3.05 ± 0.07	3.05 ± 0.04
7	2.94 ± 0.09	2.98 ± 0.07

*** Seconds**

TABLE V
Means and Standard Deviations of Height of the COM Above the Water at Take-off for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	1.39 ± 0.06 *	1.38 ± 0.04 *
2	1.26 ± 0.02	1.30 ± 0.01
3	1.40 ± 0.03	1.38 ± 0.03
4	1.43 ± 0.04	1.43 ± 0.02
5	1.42 ± 0.06	1.40 ± 0.02
6	1.51 ± 0.01	1.48 ± 0.02
7	1.41 ± 0.01	1.37 ± 0.02

* Meters

TABLE VI
Means and Standard Deviations of Height of the COM Above the Water at Entry for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	0.76 ± 0.06 *	0.78 ± 0.02 *
2	0.67 ± 0.03	0.70 ± 0.02
3	0.84 ± 0.04	0.83 ± 0.03
4	0.73 ± 0.08	0.76 ± 0.02
5	0.74 ± 0.11	0.71 ± 0.05
6	0.78 ± 0.06	0.70 ± 0.10
7	0.81 ± 0.02	0.83 ± 0.01

* Meters

TABLE VII
Means and Standard Deviations of Horizontal Velocities of the COM at Take-off for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	4.48 ± 0.52 *	4.51 ± 0.52 *
2	5.05 ± 0.80	4.47 ± 0.32
3	4.67 ± 0.32	4.82 ± 0.30
4	4.19 ± 0.20	4.41 ± 0.42
5	4.61 ± 0.51	4.48 ± 0.16
6	4.52 ± 0.30	4.70 ± 0.51
7	4.49 ± 0.41	4.54 ± 0.10

*** Meters Per Second**

TABLE VIII
Means and Standard Deviations of Horizontal Velocities of the COM at Water Entry for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	4.17 ± 0.31 *	4.36 ± 0.53 *
2	4.67 ± 0.91	4.20 ± 0.22
3	4.54 ± 0.26	4.36 ± 0.33
4	4.20 ± 0.43	4.20 ± 0.45
5	4.37 ± 0.37	4.36 ± 0.20
6	4.34 ± 0.30	4.29 ± 0.50
7	4.39 ± 0.36	4.32 ± 0.13

* Meters Per Second

TABLE IX
Means and Standard Deviations of Flight Times for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	0.43 ± 0.02 *	0.45 ± 0.02 *
2	0.32 ± 0.03	0.35 ± 0.02
3	0.42 ± 0.03	0.37 ± 0.02
4	0.39 ± 0.03	0.43 ± 0.03
5	0.43 ± 0.05	0.44 ± 0.03
6	0.46 ± 0.04	0.45 ± 0.06
7	0.48 ± 0.03	0.44 ± 0.02

* Seconds

TABLE X
Means and Standard Deviations of Flight Distance for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	1.88 ± 0.02 *	1.88 ± 0.10 *
2	1.49 ± 0.07	1.45 ± 0.09
3	1.72 ± 0.13	1.62 ± 0.06
4	1.69 ± 0.06	1.85 ± 0.10
5	2.00 ± 0.15	2.00 ± 0.11
6	1.89 ± 0.12	1.81 ± 0.23
7	2.01 ± 0.05	1.91 ± 0.12

* Meters

TABLE XI
Means and Standard Deviations of Angle at Take-off of the COM for Each Subject

Subject	Step X ± SD N = 3	Conventional X ± SD N = 3
1	55.65 ± 2.65 *	55.50 ± 2.96 *
2	58.45 ± 4.01	55.28 ± 1.97
3	56.46 ± 1.74	57.30 ± 1.57
4	53.62 ± 1.33	54.99 ± 2.34
5	55.97 ± 2.89	55.40 ± 1.15
6	55.58 ± 1.72	56.54 ± 2.98
7	55.81 ± 2.17	55.87 ± 0.70

* Degrees

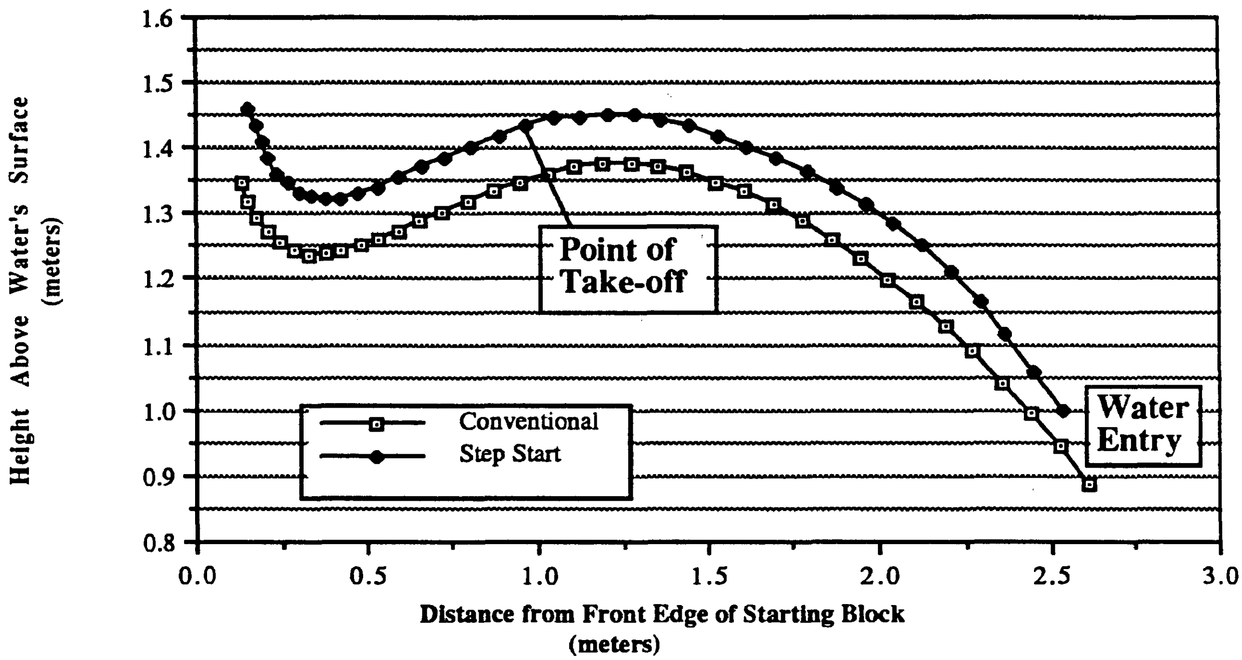

Figure 8. Path of the COM for the Step Start and Conventional Start Subject 1

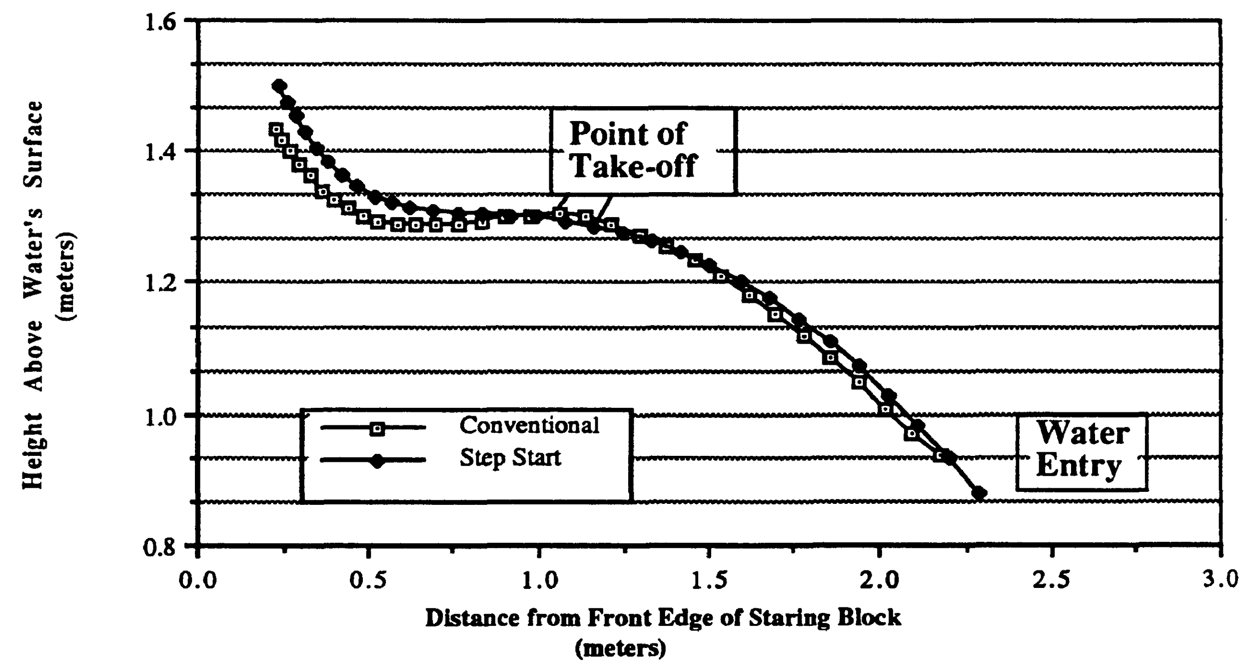

Figure 9. Path of the COM for the Step Start and Conventional Start Subject 2

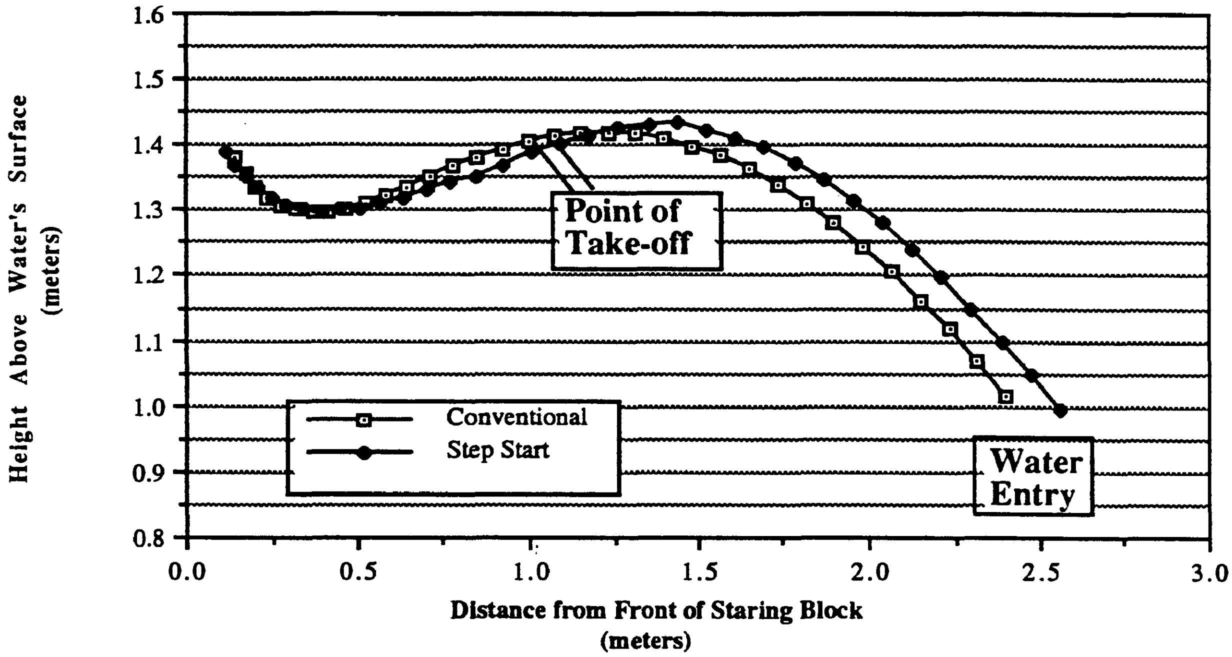

Figure 10. Path of the COM for the Step Start and Conventional Start Subject 3

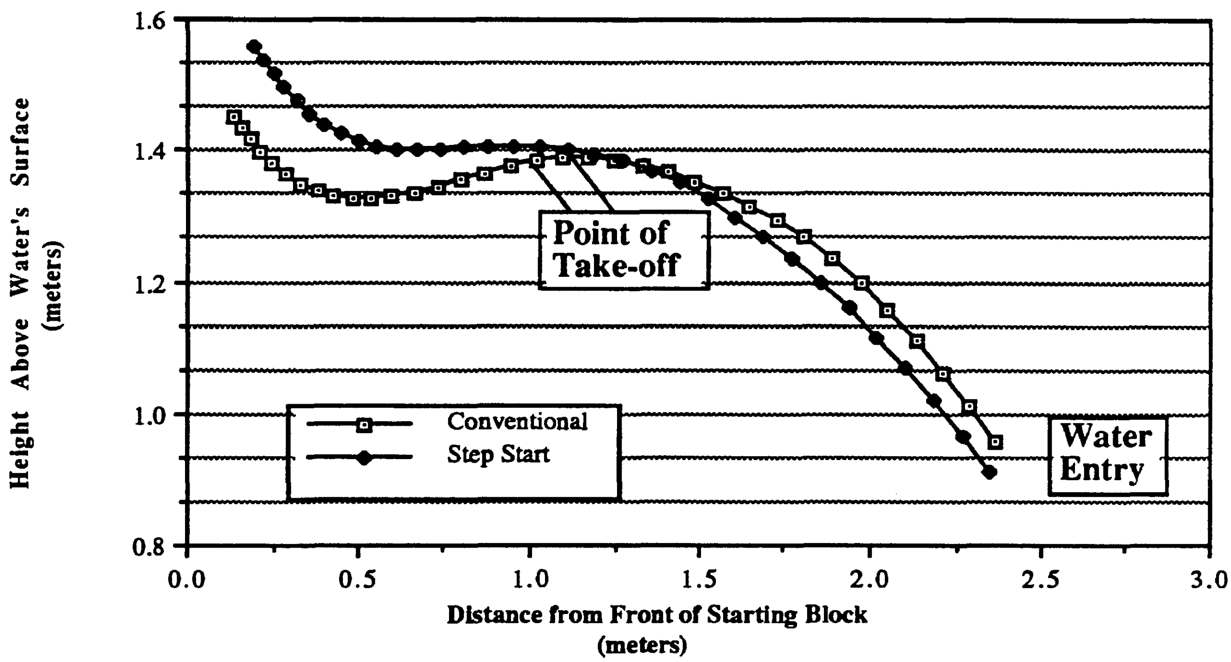

Figure 11. Path of the COM for the Step Start and Conventional Start Subject 4

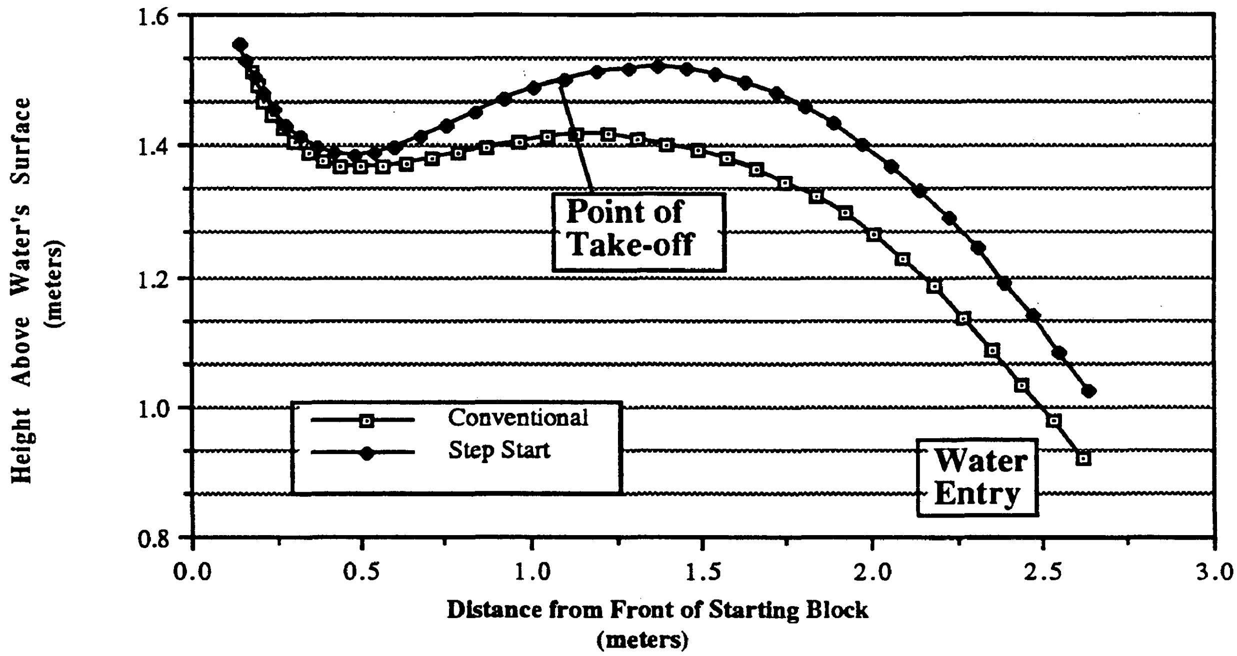

Figure 12. Path of the COM for the Step Start and Conventional Start Subject 5

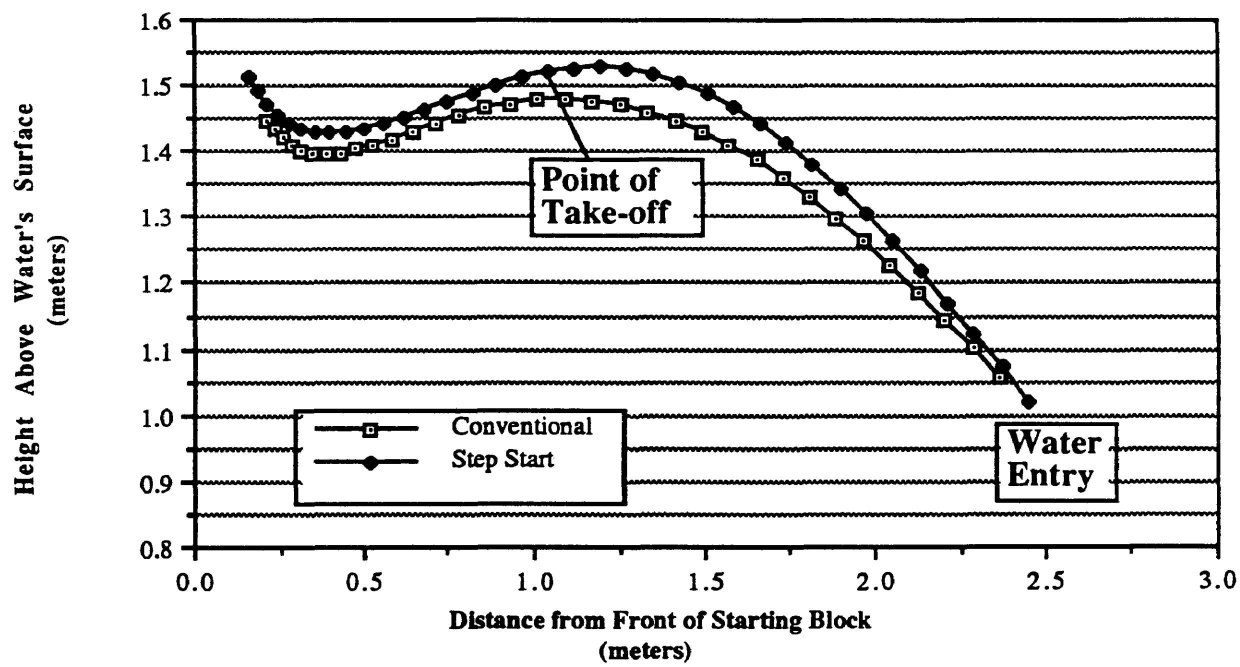

Figure 13. Path of the COM for the Step Start and Conventional Start Subject 6

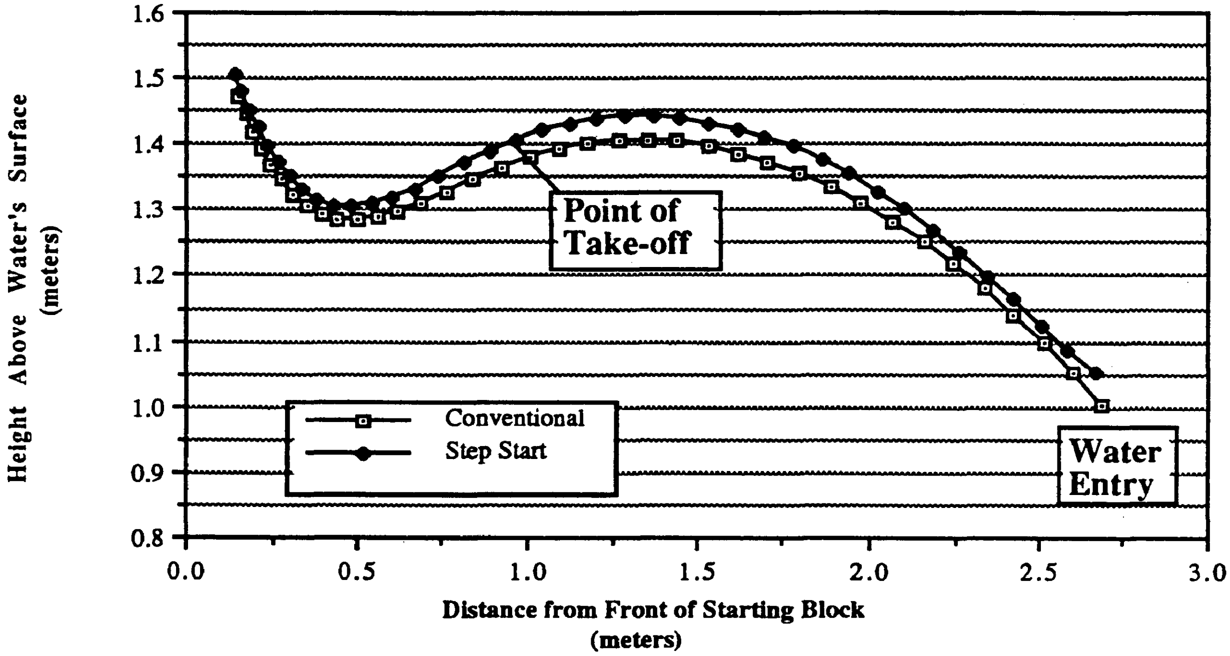

Figure 14. Path of the COM for the Step Start and Conventional Start Subject 7

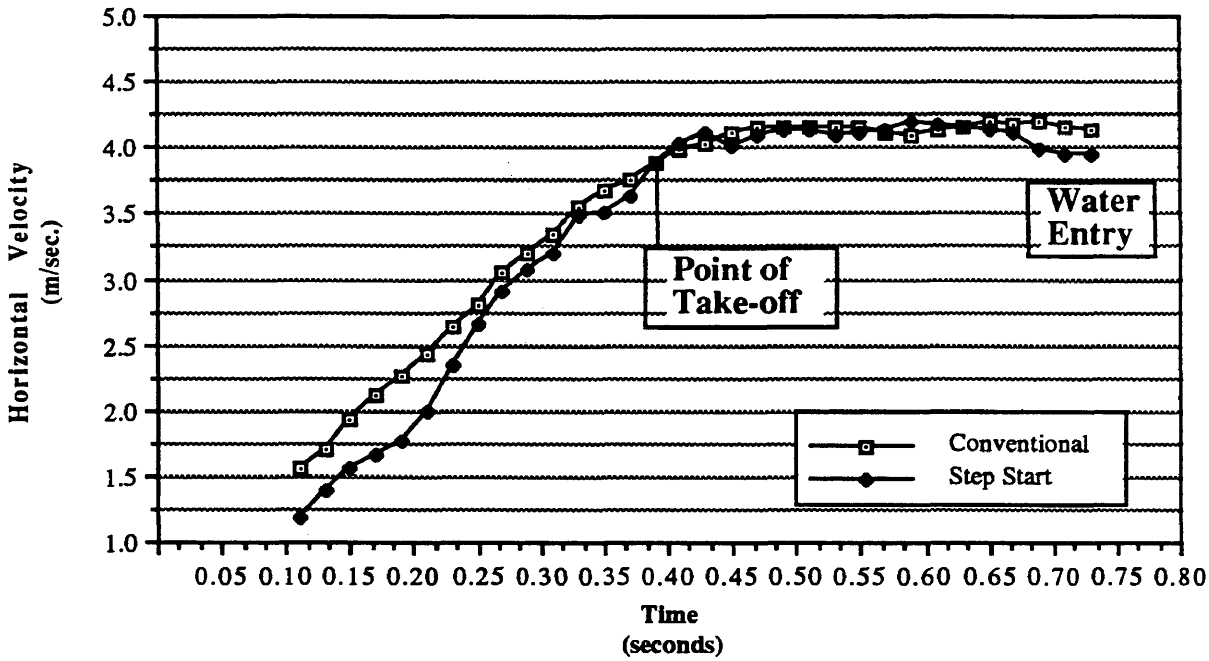

Figure 15. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 1

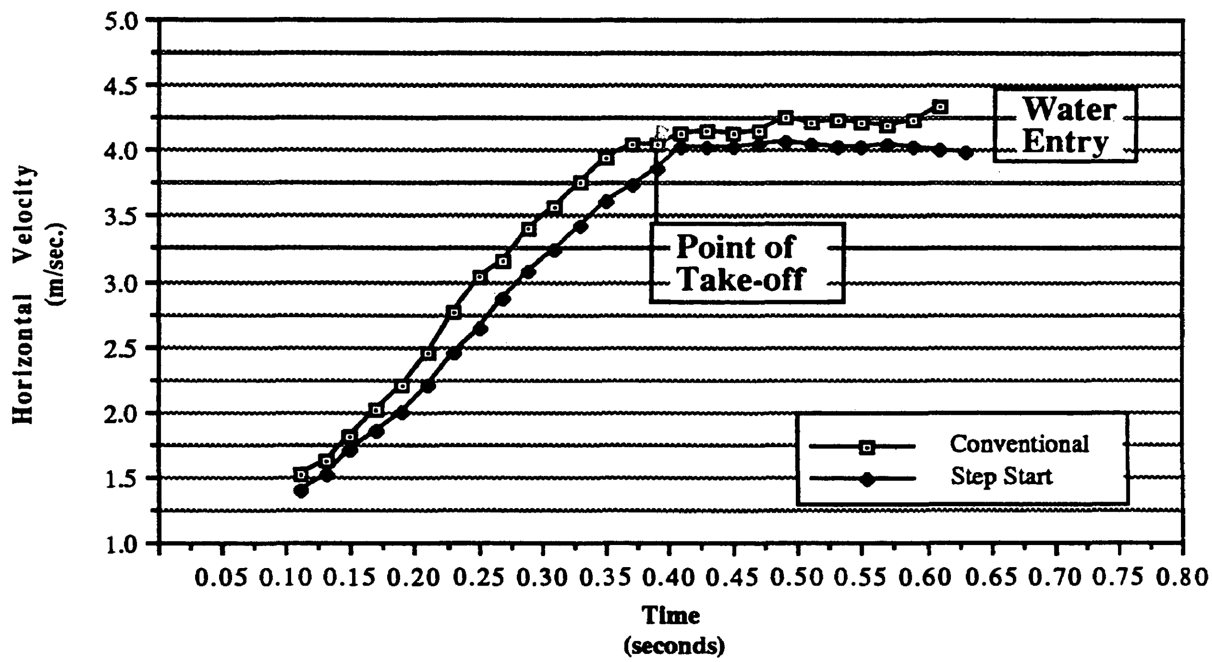

Figure 16. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 2

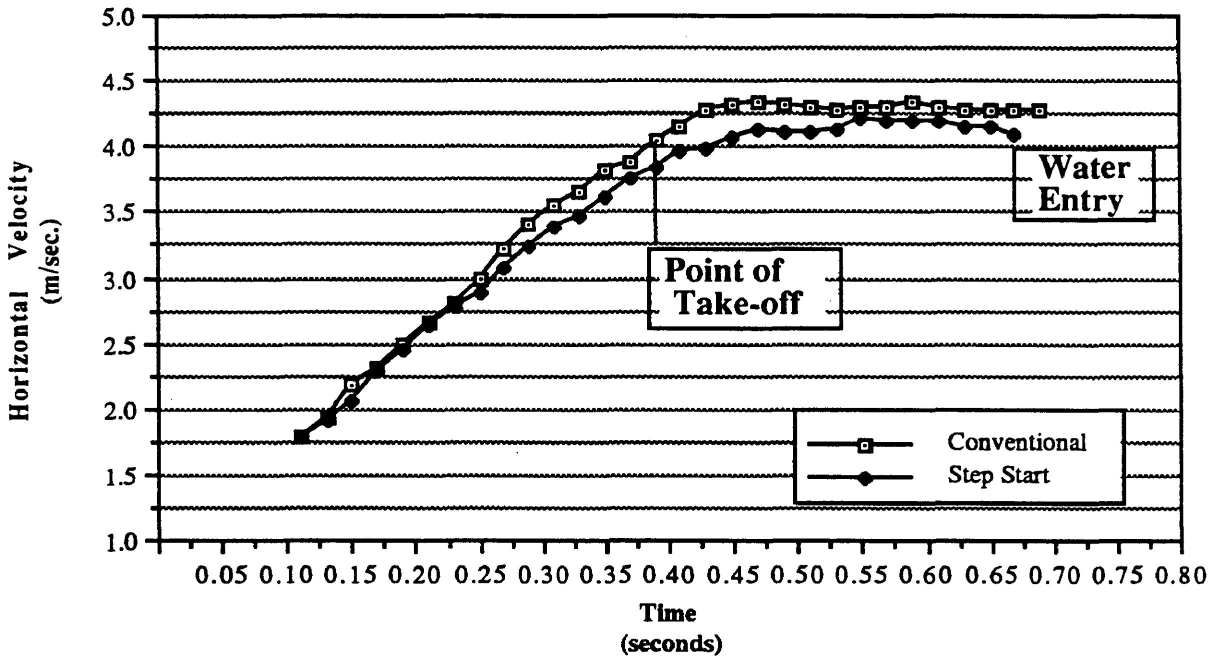

Figure 17. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 3

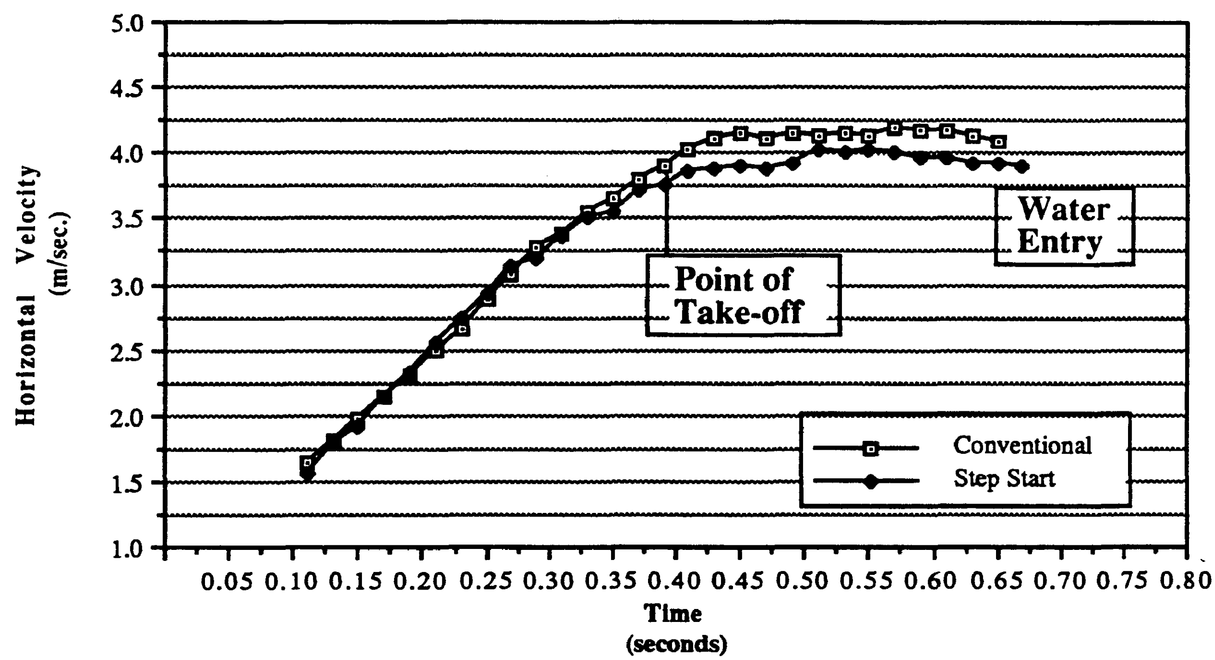

Figure 18. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 4

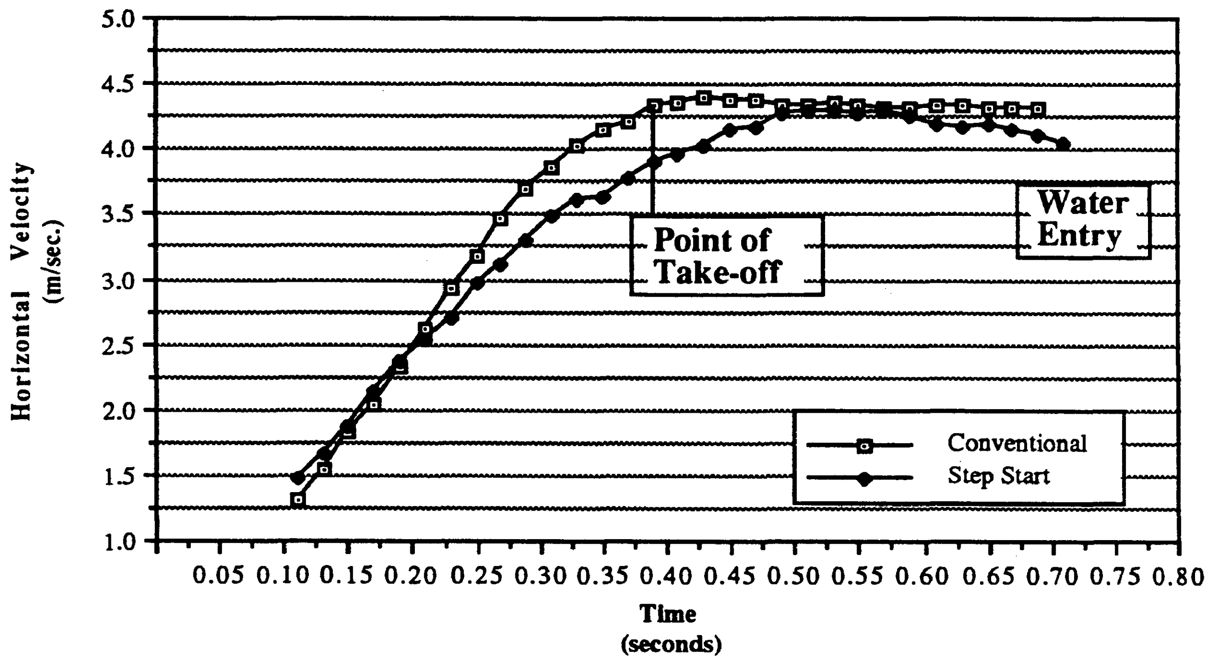

Figure 19. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 5

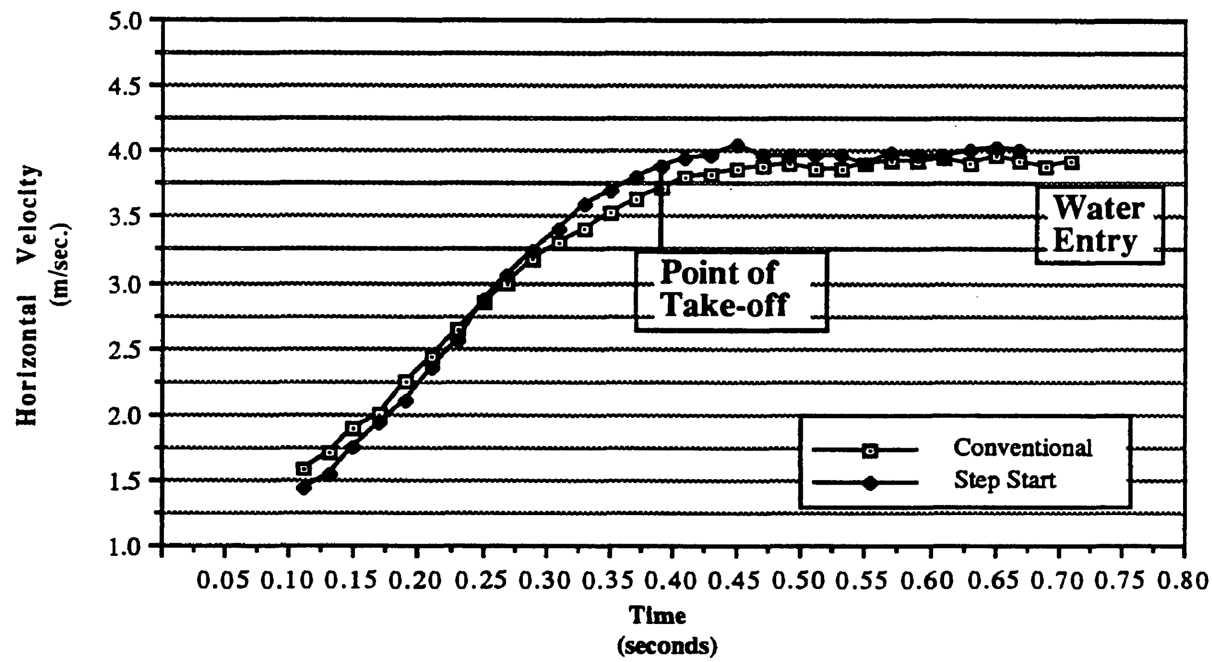

Figure 20. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 6

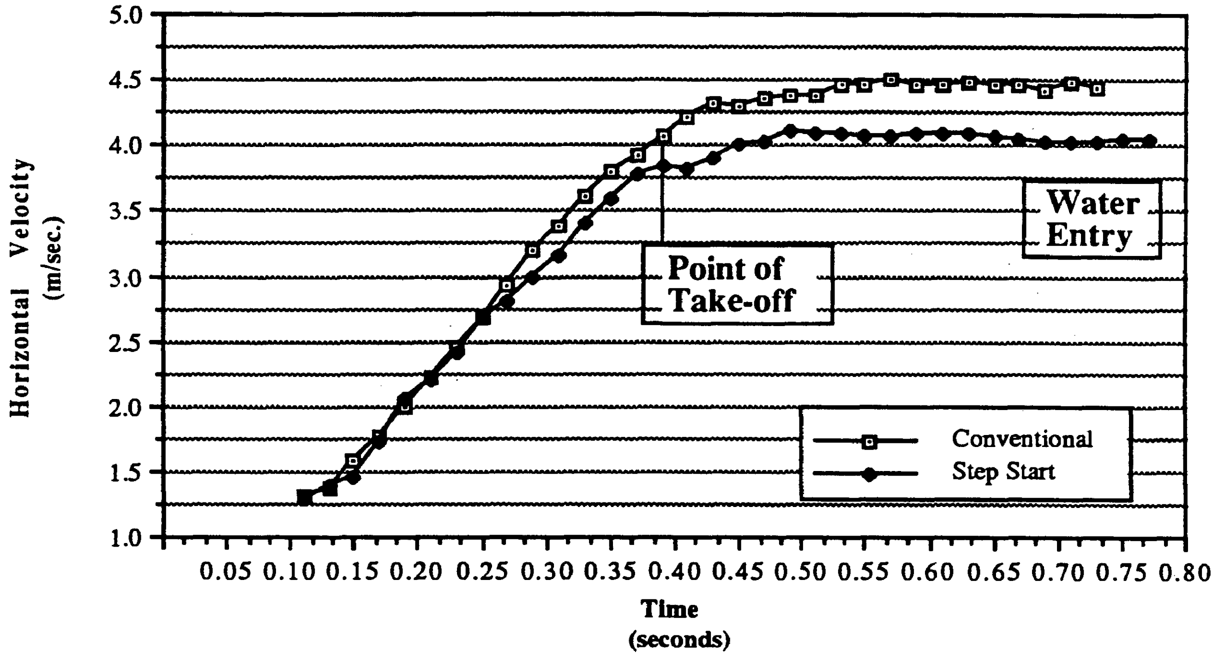

Figure 21. Horizontal Velocity of the COM for the Step Start and the Conventional Start - Subject 7