

THE EFFECT OF SELECTED VARIABLES
UPON AN EFFICIENT SPRINT START

by

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DEDICATION

This thesis is dedicated to

Barry Anderson

for all he has taught me

about track and field.

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Chapter 1

INTRODUCTION

The importance of the start is manifested in the many races that are won or lost by a tenth or a hundredth of a second. Perhaps that small amount of time was gained or lost at the start.

The development of the current methods and styles of sprint starting is most intriguing. People became concerned with the differences between individuals and how these differences affect the start, such as foot placement and the size of individuals. At first it seemed to be a trial and error situation. An excellent example of the gradual progression that took place is written by William Curtis in 1899, as taken from the Track and Field Omnibook (13:389). The focus was directed toward the start as men became more determined to race each other and win.

Several styles were in common use, the oldest being what was called the "break start". The judge stood on the starting line, the men went back fifteen or twenty paces, stood side by side, joined fingers lightly and trotted up to the judge. As they passed on either side of him, his body broke the touch of their fingers and they dashed away at full speed. If the judge thought the start fair, he said nothing, but if he thought either man had an unfair advantage they were recalled...

.....
A more complicated style was the "mutual consent" start. A line was drawn across the track fifteen or twenty feet behind the starting scratch. The men were placed between these lines and told to start by mutual consent, and whenever both men touched the ground in front of the starting scratch at the same time with any part of their persons it was considered a start...

.....
Starts of this style frequently lasted over an hour... and eventually their system was modified by inserting in the article of agreement a clause substantially as follows: "Start by mutual consent; if not off inside an hour or some other specified

time then to start by pistol." Resort to the pistol was necessary in so many cases that it gradually supplanted the mutual consent system, and became the customary way of starting sprints...

When coaches began to understand that different starting techniques produced different outcomes, they began to try new and different positions. Mike Murphy, a Pennsylvania and Yale track coach who was also the Chief Olympic track coach, takes credit for development of the crouch start. (29:32)

The crouching start was introduced by me. This was in 1887, at Yale and Charles H. Sherrill was the athlete who first demonstrated its superiority. When he used it in his first race, he was laughed at, and the starter, thinking that Sherrill did not know how to start, held up the race to give him instructions. Finally he was made to understand that Sherrill was using a new start. Sherrill immediately demonstrated how superior it was to the old standing start, which it displaced and now the crouching start is used the world over for sprinters, hurdlers and even quarter and half milers.

As people realized the importance of technique, research was done concerning specifics and how they affect a sprint start. For example. the shift from using holes in the track to the use of starting blocks was the result of research in this particular area. Likewise, research comparing the advantage of the bunch or elongated start at various points down the track has caused coaches to change the starting style of many aspiring sprinters.

A majority of the research undertaken on sprint starts has isolated a single variable from the rest of the start for comparison or analysis. The importance of foot spacing or the height of the hips above the shoulders is an example of this isolation. Perhaps this technique is not valid as it is possible to overlook the effect of some other variable that might alter the results obtained. Rather than

isolating a single variable for study, the researcher believed it was important to select a number of variables and attempt to find their affect on the start. Having the results of some of the other variables available might account for this compensation and allow for more valid conclusions.

STATEMENT OF THE PROBLEM

The problem of this study was to determine the relative effect of selected variables upon the efficiency of a sprint start as performed by female athletes.

PURPOSE OF THE STUDY

The purpose of the study was to analyze the sprint start of six female performers by use of cinematography, leg strength tests and response time tests. An attempt was made to integrate these variables with those taken from the cinematographical analysis, for example: knee flexion, angle of drive, forward lean over the line, height of the hips, spacing of the feet, velocity and response time to the gun. It was of interest to the researcher to determine which variables were important and must be emphasized or corrected while coaching the young sprinter and those which were unimportant and could be disregarded.

NEED FOR THE STUDY

There are many aspects that affect the start and, unfortunately, most of the research has handled only one variable at a time with no comparison between them or concept of how one might effect the other.

From a coaches point of view, the experience of working with a variety of athletes with a broad range of starting techniques has developed a concern as to what aspects should be emphasized. The established mechanical principles must be applied and utilized.

Most of the data currently used concerning starts was gathered on male subjects. Because of the difference in the anatomical structure of women, principles about form established for men may not be directly applicable to women. For example, relatively speaking, a woman has a lower center of gravity, a shorter segment length, a broader pelvic girdle, and less muscular strength. These structural differences will tend to influence mechanical performance.

The fact that women have not been exposed to the same level of vigorous training as men and their performances are constantly improving shows a need for research on females to be duplicated. Records will continue to be set until women are nearer their optimum level, justifying a need for more research of this nature to keep the data current.

DELIMITATIONS OF THE STUDY

The following delimitations were present in this study:

1. The subjects for the study were six female sprinters from the Kansas State University track team.
2. The skill was filmed outdoors at Christian Track at Kansas State University under a noncompetitive situation.
3. Additional tests were taken on the subjects for leg strength and response time.
5. Subjects were given no instructions on starting and used a

start that was familiar or comfortable for them. Of the six subjects, one chose to use a standing start.

LIMITATIONS OF THE STUDY

The study was restricted in the following ways:

1. The subjects used were not the best sprinters available at Kansas State University and were considered average female performers.
2. The film was taken prior to the track season, therefore the subjects had not been exposed to instruction or practice sessions which would have been desirable.
3. The use of six subjects may have biased the results.
4. The subjects were filmed only in the sagittal plane.
5. Of the takes filmed on each subject, one take was used for analysis.
6. During marking and reading of the film and transfer of data, measurement or computational errors may have occurred.
7. The test for leg strength was subject to improvement as the subject "learned" how to take the test. Grip strength affected the leg strength results as the subjects gripped a bar as opposed to using the hip belt method.
8. The subject was performing in an environment unfavorable to maximum performance. Actual competition would have been a more desirable filming time.
9. The study was limited by the accuracy and quality of the camera and other equipment used.

DEFINITION OF TERMS

Bunch Start

In the bunch start, the toe of the back foot is opposite the heel of the front foot while standing.

Center of Gravity

Within every mass there is a point about which the gravitational forces on one side will equal those on the other side. This balance point determined in three planes of the mass is the center of gravity (8:165).

Cinematography

The use of a motion camera to record motion for the purpose of analysis.

Dominant Foot

The foot placed in the rear block for starting purposes.

Dynamometer

An instrument used to measure the strength of selected muscle groups.

Elongated Start

In the elongated start, the knee of the back leg is opposite the heel of the front foot while kneeling.

Foot Strike

Foot strike is the initial contact with the ground after the foot leaves the blocks.

Medium Start

In the medium start, the knee of the back leg is opposite the front of the arch of the front foot while kneeling.

Reaction Time

Reaction time is the interval of time between a sound stimulus and the initiation of the first movement in response.

Response Time

Response time is the interval of time between a sound stimulus and the breaking of contact with the dominant foot.

Segmental Analysis

Segmental analysis is a method of obtaining the human body's center of gravity by finding the center of gravity of the segments.

Set Position

The position obtained and held just prior to the firing of the starting pistol.

Wildcat Computer Program

The "Wildcat" is a computer program, developed at Kansas State University, to calculate the body's and body segments' center of gravity and velocities while in motion.

Chapter 2

REVIEW OF LITERATURE

Research on sprint starting is as widespread as it is diverse. However, a majority of this research has been on males rather than females. The mechanical differences in starting between men and women would be affected by such things as the body's center of gravity, body weight, strength and so forth. With this thought in mind, a review of the related literature specific to the problem of this study was undertaken to establish a mental picture of the sprint start and to ascertain the affect of selected variables upon this start. The chapter was divided into areas covering the literature pertaining to cinematography, response time, leg strength and the actual start. The section on the sprint start was subdivided to include the set position, action at gunshot and action involved from the first foot strike to ten yards. A final section on the standing start was included because one subject chose to use this type of start for the study.

CINEMATOGRAPHIC ANALYSIS

Basically the use of photographic techniques for research in the study of man in motion...is the recording of an event for more careful and detailed study and, particularly, to 'freeze' the action for a certain length of time to permit careful analysis. (32:51)

This definition is very descriptive in the precise function of cinematography. Analysis of motion by the human eye contains too much error because most movement patterns happen too quickly to attempt an

accurate, detailed, or a comparative analysis of that movement. This "critical shortcoming of the eye in the comparative study of motion is the lack of permanency of the visual record." (19:8).

Murray (28:32) stated that there were three advantages to having a permanent record of the performance of a motor skill. They were: the film is more accurate than the unaided eye, measurements can be taken directly from the film, and high speed photography can slow down or stop the performance of a skill. Rapid motion can only be effectively evaluated when it is slowed down or stopped. To avoid blurring of segments that are moving extremely fast, it is necessary to film at a speed faster than the movement is occurring. In this way, analysis is more accurate as there is less guesswork involved as to the exact position of the segment. Cinematography has been proven to be very accurate in recording man's movements and has therefore become an accepted method in performing biomechanical research.

After the actual filming has taken place, information is obtained about the movement through analysis of the film. This aspect of cinematography is very tedious and time consuming, and proves to be the greatest drawback to using cinematography, that is, the time it takes to reduce the film data. Currently there are three methods used to read the film (27:156). One method consists of projecting the film image on a wall and tracing onto a piece of graph paper attached to the wall. Constants are marked on the graph paper to keep the film aligned. Another method involves the use of a Recordak film reader which projects a magnified image onto a ground glass screen. Graph paper is also used in this method to compute coordinates for the joint centers. The third way is

through the use of motion analyzers such as the Vanguard Analyzer. This machine has crosshairs that are manipulated by the researcher and placed over the joint center. The coordinates are then read from dials on the machine. There are some analyzers of this type that have access to immediate print out to the computer for analysis. This process is the most accurate and involves the least amount of time, however, it is quite expensive. The Recordak film reader seems to be the most common and feasible method for undergraduate and graduate work in biomechanics.

The possibility of error in plotting is evident. Everything possible is done to minimize this error. For example, for increased consistency in plotting the joint centers, these centers are marked on the subject with pieces of tape prior to filming. The position of joint centers of hidden segments is estimated from the movement of the segment when it is visible in frames prior to and after the analyzed frame. Miller (27:123) discussed the reduction of perspective error in cinematography.

It is also desirable to minimize the perspective error which occurs when parts of the body or sports implements lie outside the principal photographic plane. As a result, the image of the arm or leg closer to the camera will be larger than that of the corresponding limb on the opposite side of the body even though they may be identical in real life. This type of error is also present when a limb is at an angle to the photographic plane and hence appears shorter than when it is situated exactly within the plane. Although perspective error cannot be completely eliminated, it can be reduced by positioning the camera as far back from the performer as possible.

The coordinates obtained from plotting the joint centers are used in analysis of the film. From this information, such things as center of gravity of the body and its path, velocities and angles can be computed. The method used to find the center of gravity is called the segmental method. For a detailed description see Appendix A. The

reliability, objectivity and validity of the segmental method was investigated by Davis (9:21). His findings indicated that the reliability of determining the x-y coordinates of the center of gravity was $R_x=0.9682$, $R_y=0.9443$. From this study he concluded that "the reliability of the segmental method is acceptable but the objectivity of the method is valid for kinematic analysis, but not for kinetic analysis." Kinetic analysis deals with the action of forces in producing or changing the motion of masses whereas kinematic analysis deals with pure motion without reference to mass or cause.

The projected images on the screen are usually not true life size. The size of the image is found to vary directly as the distance from the lens to the screen. To adjust for this discrepancy, it is appropriate to apply what is called a reduction factor or multiplier. This can be obtained from some known dimension that is known which appears in the filming plane of the picture.

Angular measurement has the great advantage of requiring no multiplier or correction factor to obtain true size dimensions. Lines of flight, or joint centers are plotted and compared to a known horizontal or vertical and then simply measured with a protractor. Bunn (7:313) stated that "this is the most feasible method of studying the range of movement of parts of the body in all types of dynamic exercises."

According to Miller and Nelson (27), a number of factors should be considered when doing a cinematographic study. These suggestions help summarize things to remember to make the study as accurate as possible.

1. The performer should move at right angles to the optical axis of the camera.

2. The camera should be as far away from the subject as possible and use a telephoto lens to minimize perspective error.
3. Use a stationary camera position on a tripod, do not pan.
4. Utilize a plain uncluttered background.
5. Make sure the subject is familiar with the conditions of the study.
6. Don't wear bulky clothing as it hides the true shape of the body. Mark the joint centers for ease in analysis.
7. Use sufficient light to properly expose the film.
8. Make sure the frame rate is fast enough to avoid blurring in fast moving segments.
9. Start the camera a few seconds prior to the beginning of the action so as to reach the desired frame rate.
10. Include an accurate timing device.
11. Establish a scale value to convert film size to life size.

Analysis of motion by the human eye contains much error because movement patterns happen too quickly. Cinematography has employed many things to avoid this error such as faster cameras, marking joint centers and experience with position and lighting. Therefore, cinematography has been regarded as very accurate in recording man's movements and has become an accepted method in performing biomechanical research.

RESPONSE TIME

Response time can be defined as the interval of time between the presentation of the stimulus and the breaking of contact with the dominant foot. If it is believed that response time can have a significant affect upon the speed of the start, then important questions

concerning the possibility of its improvement and factors that affect it can be raised. In the literature review, there are cases where the terms reaction time and response time are used interchangeably. The findings are reported as the authors wrote them even when what they called reaction time was, in actuality, response time. Refer to the definition of terms in Chapter 1 of this study for a differentiation of these two terms as used in this research.

Doherty (13) believed that reaction time can be improved but having a fast reaction time is not a determining factor as to whether an athlete is a good or average sprinter.

Sprinters Reaction Time (time lapse between sound of gun and first movement in response) is both inherited and improvable. The inborn tendency of some sprinters is to react to sound quickly; that of others, more slowly. Further, the consensus of related research (Track Technique, March 1963, 325) is that reaction time is not correlated with speed, either out of the starting blocks or when sprinting. A great sprinter can have relatively slow reactions and an ordinary sprinter relatively fast reaction time... (13:393).

There is a difference among coaching tactics as to whether the athlete should be relaxed in the blocks and let the gun scare him out or tensed with the focus on the gun. This related to the controversy of whether a faster reaction time is obtained by putting the muscles in a state of tension. Smith (35) conducted a study where the arm was suspended in a sling and found no significant difference between reaction time when the limb was relaxed, tensed or placed under stretch.

However, most of the literature reviewed favored putting the muscles on stretch. Schmidt (31) believed that the positional tensioning "took the slack out of the muscle" which produced a lower reaction time. He found that movement time was not affected by positional

tensioning which may account for the coaches theories of sprint starting.

The actual amount of time elapsed for reaction time and block clearance time (response time) has been researched. Doherty (13) stated that with rare exception "...no man should be able to move a muscle until after one-tenth second has elapsed after the firing of the starting gun." Franklin Henry (17:30) agreed in saying that "...a typical sprinter requires a little more than a tenth of a second to react, but needs almost a full second to clear the starting blocks after the gun has been fired." Henry's research also concluded that reaction time is uninfluenced by block spacing. A mean reaction time of 0.115 seconds was found by Barlow (2). Following the starting stimulus, he found that the first segment to move was the head and neck. Dickerson (11) researched block clearance time in relation to the kind of start used. He found that the average time required to get clear of the blocks (including reaction time) was 0.244 seconds for a 10.5 inch bunch start, 0.326 seconds for a 21 inch medium start and 0.387 seconds for a 26 inch elongated start.

Nakamura (30) conducted a study comparing the time elapsed between simple reaction time and starting reaction time. He utilized 22 subjects and found that in every case, starting reaction time was slower than simple reaction time. His reasoning for these results in his study was that in starting time the whole body must be used and in simple reaction time, just a finger was raised. Another reason for the variation in reaction time was due to the strength of the stimulus such as the gun versus the sound hammer method. Nakamura also noted that differences were due to variations between the subjects such as direction of attention, habit of reaction and type of reaction.

A study on 24 college men was undertaken on the relationship between reaction time and the ability to run short, middle and long distance races by Tuttle and Westerland (39). As might be expected, he found that reaction time and ability to run short distances correlate highly and that reaction time varies with the distance of the run for which the man was trained. Westerland (41) did another study on the relationship between running events on the track and the reaction time of the runner. His test involved pressing a key in response to a light stimulus. A high correlation of 0.863 was found between reaction time and speed in running 75 yards. The subjects for the study were 22 trained trackmen, which included a world champion in the 220 yard dash, an NCAA champion in the 220 yard dash, and a high school champion in the 440 yard dash. The results of the study showed the reaction time of the various groups as follows: champions 0.121, dash men 0.131, middle distance runners 0.149 and distance runners 0.169.

The length of time between the preparatory signal "get set" and the stimulus (gun shot) had an affect on the sprinters response time and in turn, on the efficiency of the start. The importance of this element was that if the foreperiod was too short, the subject would not "get set" and if it was too long, the subjects readiness for action decreased. Most starters are told to hold the runners for a period of 1 to 2 seconds. Nakamura (30) claimed 1.5 seconds was the optimum preparatory time as found in a study he did on the start of the race.

Malcolm Stock (37) stated that reaction time is too short lived when placed in context with the complete race and is not the primary factor influencing the sprinter. But when the result is that final lean at the tape, it would seem that the sprinter would hope for every

advantage possible, including a faster response time.

An interesting thought was proposed by Charles Beck concerning the relationship of reaction time and starting time. "Reaction time may affect starting time more with inexperienced sprinters than with experienced sprinters." (3:41). It seemed plausible that an inexperienced sprinter could partially compensate for his lack of technique by a fast reaction time when compared to a similarly inexperienced sprinter. As technique was developed and improved, reaction time seemed to have less and less importance.

Research shows that it takes approximately 160 milliseconds (22:76) to react to an auditory stimulus but almost a full second to get clear of the blocks after the gun (17:30). Specific times for block clearance time were found to be 0.244 seconds for a 10.5 inch bunch start, 0.326 seconds for a 21 inch medium start and 0.387 seconds for an elongated start.

LEG STRENGTH

Leg strength was a second variable that was investigated in respect to its affect on the sprint start. It was hypothesized that perhaps it is possible for someone with greater leg strength to produce more force and hence get away from the blocks faster.

Eric Sprigings (36) did a cinematographic study on sprint starting that involved force-time recordings. He proposed that the purpose of a strong forward arm drive was to produce an early force against the blocks which would allow the leg to remain in a flexed position longer. This in turn enabled the legs to apply a force to the body for a longer period of time. He then related this proposal to the significance

of leg strength.

It may occur to the reader at this point that if the sprinter's legs were strengthened, it would permit him to continue his strong fast leg extension at the same time as the arms were acting. This would mean a greater combined force over a shorter period of time which would produce an impulse much more ideal than an impulse of the same magnitude that originated over a longer period of time...it is most evident that a large decrease in the sprinters average had occurred just as the back foot came off the blocks. This would seem to suggest that the stronger leg should be placed in the forward position since it would be more capable of exerting greater force during this critical early stage of the start when the leg is in an anatomically weak position (knee angle less than 130 degrees). (36:1561).

From his study, Sprigings drew three main conclusions. He found that more emphasis should be placed on utilizing arms, head and trunk during the start; leg strength is very necessary in order to achieve/withstand the large forces during the early stages of the start; and the subjects should put the stronger leg forward.

Jackson and Cooper (20) studied the effect of handspacing and rear knee angle on the sprinter's start. In the course of their study they also tested their 12 male subjects on ten cable tension strength tests and found strength to have an affect on the start. The five muscle groups of each leg that were sampled included hip flexors and extensors, knee flexors and extensors and ankle flexors. He used a stepwise multiple regression analysis to examine the relationship of leg strength and movement time at ten yards.

The multiple regression analysis suggests that the significant differences among the rear knee angles may be due to factors of leg strength. When the sprinter was in the 180 degree position the function of the rear knee and hip extensors was essentially eliminated from exerting force against the rear block. In contrast, the 90 degree and 135 degree rear knee positions facilitated the utilization of the myotatic reflex of these muscle groups. The findings

reported by Henry that the rear leg develops more force than the front leg during a start adds credence to this hypothesis... an analysis of the data suggests that experimental research on the nature of the relationship between leg strength and the sprinters start is in order (20:381).

The following table taken from Jackson and Cooper (20:381) shows the results of their multiple regression analysis on strength tests and movement time for their study.

Table 2. Multiple Regression Analysis of Cable-Tension Strength Tests and Movement Time 0 to 10 Yards

Step	Variable Added	R	R ²
1.	Right hip extension	.562	.316
2.	Right knee extension	.694	.482
3.	Left hip flexion	.771	.594
4.	Right hip flexion	.808	.653
5.	Right ankle plantar flex.	.935 ^a	.874
6.	Left hip extension	.952 ^a	.906

^a Significant at .05 level

Charles Beck (3) reviewed a variety of selected measurements in the sprint start including leg length, leg strength, height, weight and reaction time on 24 seventh and eighth grade boys with one year experience or less. He measured leg strength by having the subjects lie supine on a multiple angle testing unit. For his study he defined leg strength as the total amount of force by the extension of both legs during a single contraction. The subjects were tested at knee angles of 90 degrees and again at 130 degrees. He then had the subjects start and run for a distance of ten yards. The results Beck obtained showed that leg strength had no significant effect upon the sprint start. He stated that the strong and weak strength groups obtained means only 0.002 seconds apart. (3:41).

Studies on reaction time and movement time show that strength can be a contributing factor. Most research claims that strength does not significantly affect reaction time but can affect and improve movement time. Johnson and Nelson (21) found that weight training and resultant strength improves speed of movement.

From the standpoint of force and power, the more strength in the legs the more force can be developed in a short period of time. Hence, strengthening the legs would help improve starting time. However, this conclusion was drawn from the research undertaken on male subjects. The need for research on females is indicated to determine if similar conclusions would occur.

THE SPRINT START

The sprint start is composed of three positions or actions resulting from the commands of the starter. On the first command, "On your marks", the runner simply puts her feet in the starting blocks with one knee and both hands on the track (in a crouch start). When all runners are ready, the starter brings them to the next position by the command "set". This is the position where many different variables can affect the efficiency of the start. These variables will be broken down and discussed separately in this section. The next action is a result of the firing of the gun and all runners leave their blocks and the race is started.

The Set Position

Once the sprinter had gotten in the blocks "on her marks", she prepares herself for the next command, which is get "set". When this

command is given, the starter extends her legs bringing her knees off of the ground and rocks forward over her hands. This position is held until the starting pistol is fired.

Variations exist in the set position for many sprinters in reference to the height that the hips are raised, the position of the feet in relation to the starting line and to each other, how far the sprinter rocks over her hands, and how much extension is evident in her legs. These areas will be discussed separately as research has been done isolating and manipulating these variables.

Knee flexion. The angle that the rear knee is flexed while in the blocks will affect the amount of force available to push against the blocks. In other words, the leg must be positioned to achieve the greatest mechanical advantage from the large muscle groups available. Things that affect the angle of the rear leg are height of the hips, forward lean over the line and the distance of the rear block from the starting line.

Studies report a variety of exact angles proposed to result in the best start. Kinder (23) conducted a study using 120 boys ages 12 to 17 years old. He attempted to find the kinesiological advantages that exist between the position of flexion or extension of the trail leg in the starting position. The subjects were exposed to a three week conditioning and instruction program and for this study used a modified medium start (spread of 14 - 20 inches between feet). As the subjects were brought to the set position, the angle was measured, then the gun fired. The results of his study showed that the trail leg in some degree of flexion was significantly superior in terms of speed. He found that some subjects were able to clear the blocks more quickly with the trail

leg in extension, but had difficulty in maintaining good balance and proper stride. They also seemed to stand up quicker than with the trail leg in flexion.

Jackson and Cooper (20) did a study where they systematically altered the hand spacing and the rear knee angle. Two hand positions were used with spacings of 8 and 20 inches between thumbs, and three knee angles consisting of 90, 135 and 180 degrees. Subjects for the study were 12 male college freshman with no previous training. They were exposed to two 50 minute practice sessions. The wide arm position lowered the shoulders, provided a more stable base and lowered the subjects center of gravity. At the 90 degree angle, the hips and shoulders were even and by increasing the angle, the center of gravity raised and moved further forward over the base of support. The results showed that the knee angles of 90 and 135 degrees did not differ significantly, but the 180 degree knee angle was significantly slower than the other two in both sprint components. The effect of this rear knee angle was present at ten yards and still present at thirty yards.

Doherty found an angle between those found by Jackson and Cooper to be appropriate.

Place the back block at such a distance so that in the "set" position, when the high point of the back is about four inches above the neck, the angle of the back knee is 110 degrees. This angle enables the back leg to apply maximum force immediately against the back block and over a greater length of time than is possible if the knee angle were straighter. (13:400).

Gagnon (14) photographed four sprinters from the varsity track team in the set position and moving through a distance of six yards. On the basis of their competitive dash times, they would be classified as average college sprinters. He found the range in the front knee angle

to be from 82 to 103 degrees and the range of the rear knee angle to be from 93 to 153 degrees. According to Gagnon, the main factor responsible for the range was the footspacings. His findings indicated that variations in the starting position produces a significant effect upon the performance of the first stride but not upon the subsequent strides. He also found that the achievement of the fastest time in the first six yards was most closely related to the proximity of the center of gravity of the body to the starting line. One way to achieve this is to extend the rear leg and roll forward over the hands.

Another cinematographical study was done by Wilson (43) using female sprinters. She investigated the difference between the bunch, the medium and the rocket start and a variation of these three starts using an extended rear leg. She found significant differences in favor of the extended rear leg starts when the two medium starts were compared and the two rocket starts were compared.

It should be noted that the amount of knee bend at the start will depend upon the strength of the leg muscles (7:122). The stronger the muscles are, the lower the starter can dip. The research found on rear knee angle seemed to agree that it does have an affect on the sprint start. The range of tested angles was from 90 to 180 degrees with the optimum being the medium range somewhere between 110 and 125 degrees.

Height of the hips. The variables of height of hips, knee flexion, forward lean and footspacing are all so interrelated that it is difficult to distinguish where one stops and the next one starts. The isolation of one facet is very difficult without reflecting upon one or more of the other variables. However, through observation, manipulation and testing

the desired position can be obtained.

Breshnahan (5) stated that lifting the hips raises the center of gravity above the line of force along which the legs are driving. He claimed that generally the hips are slightly higher than the shoulders and the trunk gently slopes downward. Maximum force must be exerted in a near horizontal direction. If the hips are placed too high in the set position, maximum drive from both legs is difficult. If the hips are too low, maximum efficiency is again decreased. It is important to remember that the center of gravity must be kept from rising and falling more than is necessary, since energy must be expended to move it up and down as well as forward.

By having the hips higher than the shoulders, the center of gravity is thrown forward toward the hands and in front of the feet. This line between the hips and shoulders is about 27 degrees above the horizontal according to White (42). He compared a large number of sprinters starting from high, normal and low angle of hips in a bunch position and related it to starting time (interval of time between the pistol shot and where the rear foot broke contact with the block). He found that the time shortened with a high hip angle and increased with a low angle.

A study was undertaken by Stock (37) on 26 track men using various starting positions. Concerning hip elevation, he compared a medium start (16 inches with back knee angle less than 130 degrees) and a medium high hip (16 inches with back knee angle greater than 165 degrees). The subjects were timed at the 20 and 50 yard marks. The medium high hip proved to be the best. The overall superiority was derived from the forward leg power and leverage in extension, the rear leg power in flexion, the distance of joint movement and the proximal location of the runner's

center of gravity. He claims that the influence of the sprint start upon the race continues to be a factor well past 20 yards.

The general consensus seems to be that having the hips slightly higher than the shoulders has seemed to provide the most efficient start. Placing the hips in a position relative to the body's center of gravity so that a smooth drive can be obtained rather than a down and up action, as would be seen if the hips were too high, will help direct all of the momentum in the desired direction.

Spacing of the feet. The distance of the feet, both from the starting line and in relation to each other, has been thoroughly researched. The foot spacing will affect almost every other aspect of the start.

Doherty (12:14) stated that the back block should be placed so that the back leg can build up maximum force as quickly as possible and still provide adequate time in which this force can be applied. This implication of importance of velocity and power of the start being related to longitudinal spacing of the blocks was evident throughout the literature.

A study on force-time characteristics of the sprint start was done by Henry (16) in 1952. He tested subjects in ability to sprint 50 yards using a 11, 16, 21 and 26 inch foot spread. The average velocities at moment of clearing the first block was 2.20, 2.47, 2.50 and 2.54 yards per second respectively. These facts show that within the range of medium to long spacings there is little difference. However, the 11 inch or "bunch" start was about 12 per cent less powerful than the others. Henry stated that while it is true that the bunch position gets the runner off the blocks quickest, he was going slower because of his body

position as he left the blocks and never recovered from this disadvantage. He concluded that the velocity out of the blocks was of greater concern than block clearance time and that in this respect the 16 and 21 inch were best. When the front block is moved forward, the front leg has a greater time in which to apply force against the blocks and thereby increase velocity. Henry notes that although the rear leg developed considerably more maximum force than the front, the latter contributed twice as much to block velocity because its impulse had a longer duration. Another aspect of footspacing that he suggested was that leg length is not important in determining the best block spacing and is unrelated to 50 yard sprinting ability. "...it is clear that the need for individual block adjustment for different leg lengths is of no practical importance or it would have evidenced itself in the present sampling." A.D. Dickerson, however, says that "...the individual height should be a deciding factor." (11:12). The taller the man, the farther back from the starting line he sets his front block.

Twenty eight subjects from an University of Oregon physical education class were tested by Sigereth and Grinaker (34) on the effect of foot spacing on velocity in sprints. Each subject used three types of starts, the bunch, medium and elongated where toe to toe spacings were 10, 19, and 28 inches respectively. Each subject was measured at 10, 20, 30, 40 and 50 yards with each start for a total of 15 scores. Their results showed that the medium position produced the lowest mean times and the elongated start evidenced the highest times. The bunch start was significantly faster than the elongated only at 30 yards and in no instance was it superior to the medium position. They found that the largest number of fast sprints were made from the medium position

and the smallest number of fast sprints were made from the elongated position.

A similar study was undertaken by Meneley and Rosemier (26). The distinction between the types of starts was very defined but more individualized rather than a set distance. The bunch start was defined as having the toe of the back foot opposite the heel of the front foot while standing. The medium start had the knee of the back leg opposite the front of the arch of the front foot while kneeling. When the knee of the back leg was opposite the heel of the front foot while kneeling, it was described as an elongated start. The hyperextended start had the feet the same as the medium but the hands and the front foot were placed as close to the line as feasible. The distance of the front foot to the line with the other methods was 19, 15 and 13 respectively. This study entailed testing 30 subjects at 10 and 30 yards. They found that the hyperextended position showed significant lower elapsed times at both the 10 and 30 yard marks. The order of elapsed times under these types suggested that the efficiency of these starts was a function of the distance between the two feet, the wider the spread of the feet the lower the elapsed time. Some evidence presented also suggested that the efficiency of the start may be a function of the distance of the front foot from the starting line.

Research done by Gagnon (14) supported the hypothesis that with an increase in footspacing or foothand spacing, the center of gravity was farther behind the starting line enabling the sprinter to exert force on the front block for a longer period of time, thus a higher velocity was produced during the first stride. (Emphasis is again placed on footspacing in regards to power and velocity.) He also found that

the length of the first stride was a function of footspacing; an increase in the first stride was associated with an increase in footspacing.

In 1934, Kistler (24) reported that the force applied by the front leg in a variety of starting positions was relatively constant. As the foot spacing increased, the back leg force increased and subsequently the sum of the forces of the front and back leg increased.

An interesting phenomenon was observed by Breshnahan (4) in a study on foot position relative to handedness. He observed that right handed sprinters have a tendency to put the right foot in the rear blocks and left handed sprinters put the left foot in the rear blocks.

Lloyd Winter (44), one of the United States Olympic coaches, made a film analysis of Armin Harys form in the 1960 Olympic games. Hary, of Germany, won the sprint supremacy of the world in the 1960 games. Winter later field tested the idiosyncracies of his start and found in each case to have a definite contribution toward faster block clearance and faster pick up. Hary's blocks were placed farther back from the starting line than the other sprinters which gave him a lower body angle, a longer early stride and a better early running position. He had the fastest start and amazing pick up in the first 20 yards.

From the literature it would seem that the effects of footspacing are important and the best range was between 16 and 21 inches which was considered a medium start. Simply changing this aspect of a start will not transform an average sprinter to a highly skilled sprinter. "With block spacing held constant, speed in the sprint is significantly related to how close the individual approaches the ideal start." (16:318). That is to say, footspacing is significantly related to the degree of perfection with which the performer has mastered the skills of starting.

Forward lean over the line. Information concerning the significance of forward lean to starting efficiency was quite limited. Other variables, though not necessarily more important, seem to attract the researchers on sprint starting.

Stock (37) claimed that any start which places the runner's center of gravity 6 to 12 inches nearer the starting line than his opponent will give him an advantage, at least in the first step or two of the race. He was not necessarily advocating the lean over the line, but this motion would move the center of gravity closer to the starting line while maintaining the proper balance to drive out of the blocks. Moving the feet closer to the line would also move the center of gravity closer to the line, but with some loss in balance and control once the runner has left the blocks. In Gagnon's (14) study, it was found that the location of the center of gravity in the set position relative to the starting line was significantly associated with time at 2.5 and 6 yards.

A definite description of forward lean was given by Brother (6) who stated that in the set position the shoulders should be between 6 to 8 inches forward of the line. The only author who found no relationship between angle of forward lean and success in the start in the review of literature was Wilson (43). She did a cinematographical analysis of women sprinters filmed in six starting positions.

The mechanical principle governing quick movements in one direction dictated having the center of gravity near the forward edge of the base of support or in the direction of movement. This can be accomplished by moving forward over the line. The sprinter must construct a style which emphasizes body forward, not up. Maximum acceleration requires forward lean (13:400). The only precise amount of lean found was between

6 and 8 inches forward of the line. It must be remembered that this figure was acquired on male subjects and would vary for females because of body size.

Action at Gunshot

At the start of the race when all of the sprinters are in the set position and are motionless, the gun is fired. The sprint start is a very explosive motion and the arms and legs are driven forcefully to get the sprinter to his running position. Discussion in this section will be divided into three parts. These are: action of the arms, action of the legs, and angle of drive.

Action of the arms. The arms are of greater importance in the start than is sometimes realized. If the arms are driven with speed and force, the legs will naturally follow.

Arthur Duffey, Georgetown Champion (1900-1903) emphasizes that "often the arms are not used to full advantage", that the primary push comes from the front leg although "both legs must be called into action at one moment", that "at the report of the pistol, the left arm is swung directly ahead, flexed at the elbow, the right arm swinging directly backwards"; and, lastly, that there is "the necessity for forward action by lifting the knees in a straight line and jabbing directly downward, without any of the side deviation which is such a common fault with the novice sprinter." (13:391).

The direction each arm is swung of course depends upon which foot is forward. It is important to note that the arms are driven forward, not up. The sprinter should drive the arms in the direction she wants to go through her line of drive. Brother (6:1293) gave two reasons for this forward drive of the arms. He stated that as the knee straightens, the opposite arm shoots forward, both to maintain balance and to keep the shoulders low. This will, in turn, aid in achieving the proper

angle of drive from the starting position.

Action of the legs. The action of the rear leg is subject to much controversy among coaches and researchers alike. For example, Brother (6:1293) believed that the drive from the rear leg at the start should be the first point a sprinter is taught about starting from the blocks, and the only thought in the sprinters mind when starting. He opposed the thought that the rear foot is "picked" off the blocks thus leaving the driving action to the front foot. Brother maintained that the rear knee straightens before the foot leaves the block, showing drive. Tests have shown that before moving from the block, the rear leg was capable of exerting a force of 125.2 pounds of weight against the block (6:1293). Newton's third law of motion indicates that the block in turn will exert an equal and opposite force on the foot, and so on the whole body.

Some authors believed the force came from the simultaneous drive of both legs. Henry (17:30) believed that in order to achieve the most powerful start, the sprinter must not only thrust as hard as possible with both feet, but must continue to thrust until his forward movement causes him to lose contact with the blocks. His thrust on the rear block will last only about 0.16 seconds since he must bring this leg forward to be on the ground for the first stride. The front foot should start to thrust simultaneously with the back and continue at full force until the forward movement pulls that foot off the block, a matter of 0.40 to 0.43 seconds (17:30).

Stock (37), on the other hand, claimed that the "function of the rear leg is to pull out of the starting blocks rather than drive against the blocks as the forward leg does." An article in Scholastic Coach (25)

stated that at the sound of the gun, the sprinter should drive hard and fast with the front leg and shoot the back leg forward just as fast as she can. The author likened it to imagining that someone had just touched the runners bare instep with a piece of ice and he is trying to get his foot away from it.

Out of these two seemingly opposite ideas, Doherty (12) seems to find a suitable reasoning for the action of the rear leg. He claimed that slow and fast sprinters do not differ significantly in the length of time that the back foot stays in its block, but fast sprinters generate a much greater force more quickly. The primary function of the back leg should be to initiate action as powerfully and quickly as possible. He pointed out that in the beginning stages, the sprinter will stumble, but she must learn to bring the knees up and under. She should keep the eyes and head down and reach out with the feet; at this stage they will always be behind the center of gravity.

Angle of drive. The reader has probably heard coaches complain about poor starting techniques concerned with the angle of drive, such as standing up out of the blocks or stumbling out. These are the two extremes involved in starting and the proper angle of drive being between these two points.

The body needs to be in a direct line with the legs through the so called angle of thrust. In this way, the legs are applying maximum force in the desired direction. Gagnon (14:2) stated that

"...the efficiency of the start is not completely dependent upon what occurs during the first stride. Some runners may require more time to leave the blocks, but because they have applied force against the blocks for a longer time and at an optimum angle, they may achieve a greater velocity..."

He also claimed that an increase in footspacing was associated with an increase in takeoff angle. This takeoff angle increased through four strides with an indication of a plateau at the fourth stride.

A common drill that coaches use to teach the correct angle of drive and to make the sprinter more powerful out of the blocks is called a resistance start. In this drill, the coach puts her hands on the shoulders of the runner while she is in the blocks in the set position. As she drives out of the blocks, the coach gives enough resistance to make the sprinter drive, but she gradually backs up. If the coach can easily push the starter either up or down, she knows she was not driving at the proper angle. When the sprinter practices driving at this correct angle with her legs in line with the line of force long enough, it will begin to come naturally.

Foot Strike to Ten Yards

The actions initiated at gunshot will have an affect on what occurs from the first foot strike throughout the race. A continued drive is needed in order to obtain maximum velocity. This section is divided into two parts: length of stride and use of arms and legs.

Length of stride. "Since a runner is gaining speed only while his feet are pushing against the ground, he should take relatively short stides when greater acceleration is needed and gradually increase his stride until top speed is attained." (7:122). If the sprinter attempts to take long strides when she is immediately out of the blocks, it will take her longer to accelerate to top speed and it will be hard to make up this deficit, especially if it is a short race.

By the time the sprinter has run ten yards, she should be in

nearly her normal running position and at full stride but still accelerating. A detailed description of running form and full stride, however, is beyond the scope of this study.

Use of arms and legs. The description of the use of the arms in the section "Action at Gunshot" is also applicable here. The arms continue to drive and are a major factor in attaining speed, power and balance.

The speed and power available from the legs will aid in achieving maximum velocity as quickly as possible. The legs must drive hard and fast and extend clear through the toes. The knees are brought up and under for the next stride.

THE STANDING START

Generally regarded as the preserve of beginners who have not yet "graduated" to the crouch start, and of middle and long-distance runners, whose starting requirements are easily satisfied, the standing start has been little used by top sprinters since the crouch start came into vogue some 70-80 years ago. (15:403).

Although a majority of sprinters utilize a crouch start, those that choose to use a standing start claim it has many advantages. Studies on the standing start also promote its benefits.

A vertical starting block was constructed by Kolker and Dooley (25) which gave the runner a higher set position when on his marks. They had two hand grips placed so that the runner's starting position approximated his running position. The subjects were tested over five and ten yards. The results of the study showed significant improvement in starting and performance time, however, the NCAA ruled that the block was an artificial aid and did not conform to the rule on rigidity and ruled it illegal.

A similar study was undertaken by Humphrey (18) utilizing an experimental semi-standing starting position. Supposedly the set position in the semi-standing start enabled the runner to start with a long stride and attain an upright sprinting position without the customary two or three steps which normally have to be taken to gain control and balance from a crouch start. Humphrey claims that most of the power seemed to be applied in a forward direction and apparently not much energy was wasted in holding up the head and shoulders or in maintaining balance. Strain and undue tension of the fingers, neck and arms seemed to be decreased. He maintained that maximum forward thrust and economy of motion, the prerequisites to a good sprint start and the purpose of the new position, could improve the performance of any sprinter. Subjects for the study were 15 untrained males who each attempted 18 crouch and 18 experimental starts. Trained sprinters were eliminated from the study to alleviate the bias towards the crouch start. The results of the study showed 11 of the 15 subjects with a slightly faster mean time using the standing start, 1 out of the 15 with slightly faster mean times using the crouch start and the remainder had the same mean time for both methods. However, this difference in mean sprinting times was not statistically significant.

Major John Short (33) tested 30 sprinters over 50 meters using a standing start and 26 immediately improved by no less than 0.2 - 0.3 of a second. For his study, he constructed a longer block (10 inches) for foot support. The angle of the front block was approximately 45 degrees and placed two inches from the starting line. The rear block angle was approximately 80 degrees and placed two to four inches to the side and plus or minus 20-24 inches to the rear of the front block. He

found the angle of the legs to be 90-95 degrees for the front leg and 115-120 degrees for the rear leg.

The standing start block gave firm footing, a flat foot drive and a stability in balance in the set position with the center of the chest directly over the front knee. According to Short, the initial drive comes from the rear heel against the block, giving the initial impetus to the center of gravity in order to get it in front on the supporting base and simplifying the front leg drive. It was noted that an initial retardance of reflex action occurred after the gun, but in all cases despite the slow reflex, a faster time was recorded over 50 meters.

The athletes in the study claimed to be more comfortable in the stand than in the crouch start. They stressed that unnecessary motion was eliminated and it was less of a strain. They reached natural running action much easier and obtained top speed much sooner. Due to lack of electrical precision timing devices for more accurate measurements, nothing was considered conclusive in Short's study other than the popularity of the standing form.

A list of advantages of the standing start was compiled by Suryanarayana (38:1595). They are: 1) the athlete runs less distance by starting closer to the line, 2) body position is initially in a nearer running posture, 3) as arms move vigorously, athlete immediately gets into effective running action, 4) the power limbs are mechanically correct, angled for efficient pulling of the muscles into the run, 5) opposite arm-leg position is more natural and comfortable to get into nearer running form at once, 6) the athlete reaches peak speed much quicker than in crouch and 7) experiments show faster times over the first 50 yard mark by no less than 0.2-0.3 seconds.

From the current research available, the standing start seems to be an effective starting technique. Tradition has dictated the use of the crouch start and only through more research and experimentation can changes be made.

SUMMARY

Sprinters who develop a strong start are on the average more likely to cross the finish tape sooner than weak starters, when block spacing is held constant (16). Even with the stipulation of constant block spacing, the thought of winning a race because of an efficient start has caused athletes, coaches and researchers to spend many hours delving into this theory.

It was the intent of this chapter to review the literature on variables that might affect the efficiency of a sprint start, these being response time, leg strength and variations in a sprinter's form such as rear knee angle, height of the hips above the shoulders, foot-spacing and forward lean.

The literature on cinematography was reviewed and found it to be a valid method for observing and analyzing human movement. It is currently an accepted method in performing biomechanical research.

Research shows that it takes approximately 160 milliseconds (22:76) to react but almost a full second to get clear of the blocks after the gun (17:30). Specific times for block clearance time were found to be 0.244 seconds for a 10.5 inch bunch start, 0.326 seconds for a 21 inch medium start and 0.387 seconds for a 26 inch elongated start. Response time seems to lose most of its effect on the sprint start as the sprinter becomes more experienced and may have even less meaning

when placed in context with the whole race. However, for sprinters with equal ability, a faster response time will get them out of the blocks and to the finish line faster. The literature indicated that increased leg strength could have a positive affect on starting time and force.

The literature pertaining to rear knee angle showed a range in angles from 90 degrees flexion to complete extension of 180 degrees. No definite angle was established as correct but the extremes were eliminated and a much smaller range of between 110 and 125 degrees was found to be most effective. The hips should be slightly higher than the shoulders and the sprinter should lean approximately 6 to 8 inches (for males) over the line to get the center of gravity closer to the line.

The literature was not consistent on the best footspacing for the start as it depended on the criterion selected for efficiency. The "bunch" start was the quickest but a "medium" start provided more force and allowed for a better position and balance when the sprinter cleared the blocks. All things considered, the best range was between 16 and 21 inches which was considered a medium start.

Since the aim is to start quicker and with the greatest amount of force, the position that would provide this result would be one with the hips elevated above the shoulder, the feet in a bunch start position and the center of gravity ahead of the feet. (7:122).

The arms and legs are driven forcefully at gunshot with the knees brought up quickly under the body for the next step. Current research seems to promote the standing start as an effective starting technique with many advantages over the crouch method. A great variation was found in sprinters styles and it was concluded that it is important that a sprinters style be mechanically correct in all respects, but it crucial that he masters his own style, whatever it may be (13:400).

Chapter 3

PROCEDURES

The problem of the study was to determine the relative importance of selected variables upon the efficiency of a sprint start as performed by female athletes. The purpose of the study was to analyze the sprint start of six female performers by use of cinematography, leg strength tests and response time tests. An attempt was made to integrate these variables with those taken from the cinematographical analysis, for example: knee flexion, angle of drive, height of the hips, spacing of the feet and response time to the gun.

Filming of all subjects took place on one day. For the convenience of the subjects, the leg strength and response time tests were conducted on separate days and all subjects were tested at each respective session. Having all subjects tested on the same item on the same day helped to control discrepancies between subjects due to time of day, motivation, weather conditions and so forth. The following pages contain a detailed descriptive account of all procedures used in this study. The chapter will be divided into the following categories: subjects, leg strength testing, response time testing, filming procedures and film analysis procedures.

SUBJECTS

Subjects for the study were six white female athletes from the Kansas State University women's track team. All subjects had been

involved in high school track programs and two of these had track experience at the collegiate level. Many had been involved in state, regional and national competition.

Filming and testing took place at the beginning of the school year before the track program had begun. Therefore, the subjects had not been exposed to instruction or coaching of their start nor had they practiced and refined their starting skills.

All subjects were measured for the length and girth of their body segments. Additional personal information such as height and weight were obtained and all data was recorded on a subject data sheet (see Appendix B). The length of the upper arm in all subjects was used as a measurement unit as it was directly in the filming plane.

For greater accuracy and ease in reading and analysis of the film, the subjects were marked with white pieces of tape with a black dot at the center. The following specific joint centers were marked on the left side of the body: acromion process, lateral epicondyle of the humerus, styloid process of the ulna, lateral epicondyle of the femur and the lateral malleolus of the fibula.

The subjects set the blocks at a distance that was familiar and comfortable for them. The distance from the starting line to each foot was measured and it was noted which foot was in the front and rear blocks. The determination as to the type of start used by each subject was made in accordance with the spacing of the feet and the definitions used in this study. Before the subjects were filmed, each read and signed the Informed Consent form. An example of this is in Appendix C.

LEG STRENGTH TESTING

The tests for leg strength were conducted in the Physiology of Exercise Laboratory at Kansas State University. The equipment used for testing was a leg strength dynamometer.

Handouts were given to all subjects with specific instructions for the test. A copy of these instructions is contained in Appendix D. In addition to the handouts, a verbal explanation and demonstration was given by the researcher.

The subjects were told to bend the knees to approximately a 120 degree angle with the back and arms straight. The bar was gripped with a mixed grip, which means one hand is forward and the other is facing back. The subject then attempted to straighten her legs. Each subject was given two trials with the best score counted as the subjects leg strength.

RESPONSE TIME TESTING

The tests for response time took place in the Biomechanics Laboratory at Kansas State University. The equipment used for this test was a Dekan Timer Model 631 and a 22½ inch by 13½ inch foot pad. The researcher ran the equipment for all subjects to equalize testing procedures. An additional person was used as a recorder.

As in the leg strength testing, a handout of instructions was given to the subjects for the response time testing. A copy of these instructions is contained in Appendix E.

Because the rear foot in the blocks is the first to move upon sound of the stimulus, this foot was used for response time testing on

all subjects. Two subjects used their right foot and four used their left foot. The justification for using this foot was to have a parallel between the two tests on each subject by using the same foot in both cases. There is a high correlation between reaction time and handedness or footedness, so it would have been the same for the other foot. For this reason, the results have not been biased by use of different feet between subjects.

For the response time test, the subject was instructed to stand with the appropriate foot in the center of the Dekan pad with her weight evenly distributed between both feet. The other foot was placed beside a mark placed four inches from the edge of the Dekan Timer foot pad. Her feet were therefore about $10\frac{1}{2}$ - 11 inches apart. At the sound of the buzzer she was to raise this foot from the pad as quickly as possible. The time clock started at the sound of the buzzer and stopped when contact was broken. The subject was given a preparatory signal "ready" at a variable interval of one to four seconds before the stimulus. Each subject was given five practice trials before any score was actually recorded. Fifteen trials were given to each subject with the mean of these trials being recorded as the subjects response time.

FILMING PROCEDURES

Filming took place at Christian track at Kansas State University and all subjects were filmed on the same day. At least three trials were taken of each subject. Additional trials were recorded if there was a bad start, a slip of the blocks or a portion of the start was missed in the filming.

All subjects used the same set of Arnett starting blocks set to

their own foot spacing and preferred distance from the starting line. A piece of tape was placed on the track 15 feet from the starting line as a reference point for the sprinters to run to.

All filming was done with a 51-002 Redlake Locam 16mm camera. The camera was equipped with a 25mm lens, a reflex lens bore site, and a variable film speed control which was set at 200 frames per second. The camera was loaded with a 400 foot reel of black and white Kodak 4X Reversal 7277 film with an ASA of 400. The lens aperture was set at f/16 and the shutter factor was set at 160 degrees.

The camera was positioned and leveled on a heavy duty tripod so that the camera was filming perpendicular to the direction of the track. The camera was placed 59'1" away from the center of the lane that the sprinters were running in. The lens of the camera was at a height of 46 inches from the ground.

A timing clock was placed behind the sprinter's starting blocks at a distance of 66'3" from the camera. This clock was readable to 0.01 of a second accuracy. The starter stood with the pistol directly in front of the timing clock to make sure the flash of the gun was recorded on the film.

Two sets of numbers were used in the filming, these being subject numbers and trial numbers. Each subject was assigned a subject number determined by the order of filming. These numbers were set against a leveled hurdle placed in a lane next to the sprinters lane on the side opposite the camera.

It was suggested that all subjects warm up well, but the time and amount of warmup was left to their discretion. Starting blocks were

available for practice but no coaching or starting suggestions took place. After the subjects were marked, they were told they would be started as if in an actual race and they were asked to put out a maximum effort. Subjects were told to disregard the sound of the camera as it was turned on. The camera was turned on after the starter had brought the sprinter to the "set" position and turned off after she crossed the tape mark on the track. The subjects were filmed in the sagittal plane moving from the right to left. A diagrammatical representation of the equipment setup is included in Figure 1.

FILM ANALYSIS PROCEDURES

The film was taken, processed, then used for gathering the data. The steps used in this process are explained here.

Gathering the Raw Data

The film was viewed on a Lafayette Analyzer and with the aid of Barry Anderson, Women's Track Coach at Kansas State University, the best take of each subject's start was chosen on the basis of form. All takes were then reviewed to see which takes of each subject were the fastest from starting flash of the pistol to a selected point on the track. In all cases, the takes chosen by form and by speed were the same trial.

The film was then spliced on the Craig Editor Splicer to include only the best trial of each performer for analysis purposes. These trials were viewed and a decision made as to the first and last frames to be analyzed. The investigator analyzed every tenth frame until the second foot touched the track and every twentieth frame until the torso of the subject crossed the plane of a specified mark on the track. This mark

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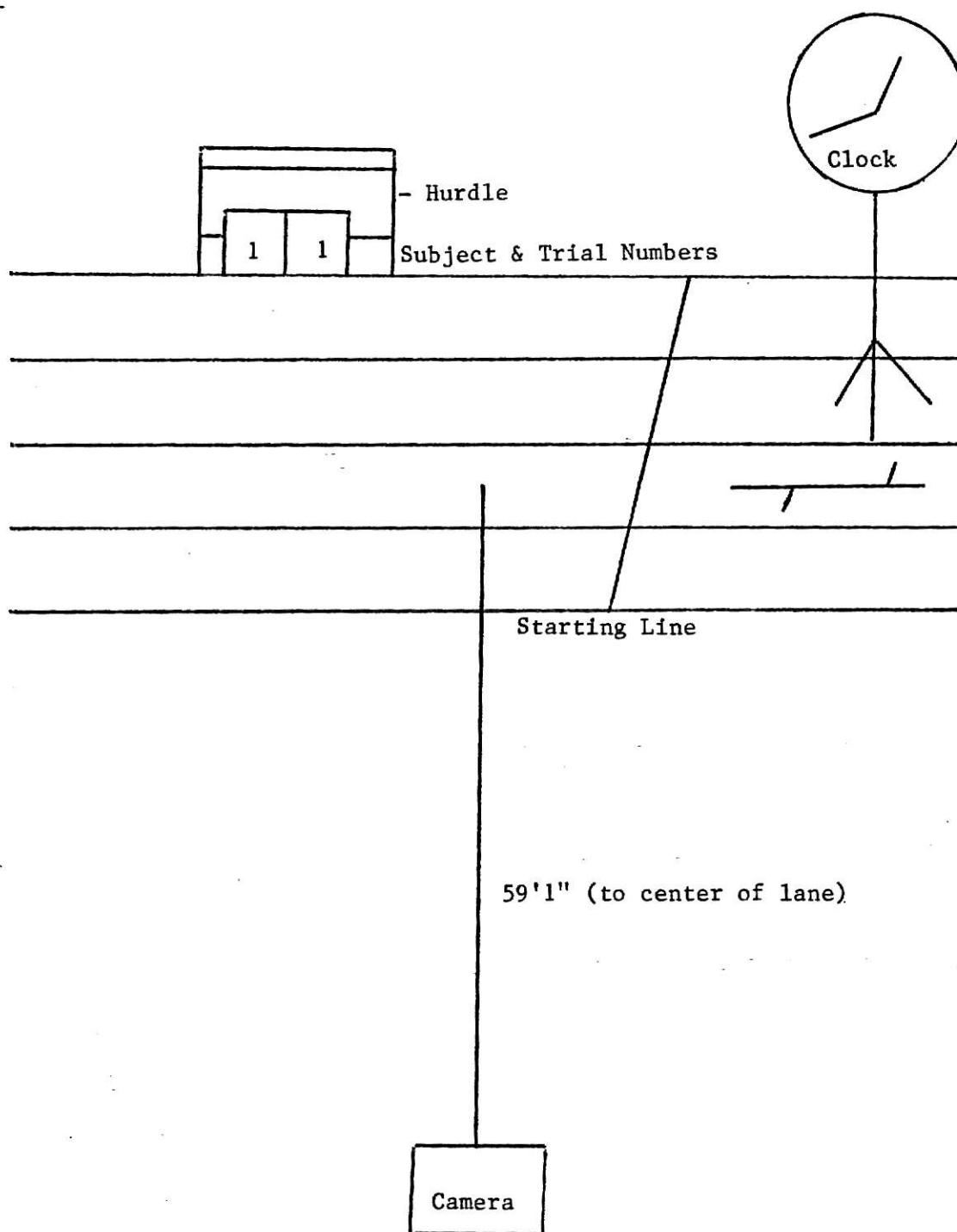


Figure 1. Diagrammatic Representation of the Equipment Setup During the Filming of the Sprint Start.

was designated by a vertical line drawn on the second railing behind the runner from the left edge of the film. Specific points in the start were located, such as foot strike. Since this might occur in a different frame from one subject to the next, it could have involved including an extra frame for analysis. When this was the case, the time was noted on the clock for frame identification.

The image of the subjects was enlarged by a 16mm Recordak film reader and projected on a piece of graph paper. The horizontal and vertical components of the hurdle were used as constants to keep the film aligned and in exactly the same place in relation to the sprinter as the reel was moved from frame to frame.

A horizontal (x) and vertical (y) coordinate system was used to plot the joint centers and their movement for use in computation. The body segments recorded from the x and y coordinate system include: head and neck, trunk, right upper arm, right hand, left upper arm, left lower arm, left hand, right lower arm, right upper leg, right lower leg, right foot, left upper leg, left lower leg, and left foot.

From the measurement unit used on each subject, a multiplier was calculated by the formula: $\text{multiplier} = \text{life size} / \text{projected size}$. This figure was used to change measurements from the film to life size.

Analyzing the Raw Data

When the collection of raw data was completed, specific factors were selected for analysis. Variables considered important to this study included the following: path of the center of gravity, angle of drive, knee flexion in the set position, height of the hips above the shoulders, spacing of the feet, velocities, response time to the

stimulus (gun) and forward lean over the line. The procedures for determining these variables is discussed below.

Path of the center of gravity and velocities. After the joint centers were plotted by use of the xy coordinate system, the center of gravity was figured for each frame by use of the segmental method. For an explanation of this method, see Appendix A. All center of gravity and velocity information was obtained through the computer center by this method. Cards were punched with the coordinates of the joint centers and run through the Wildcat Computer Program to obtain center of gravity coordinates for each frame on every subject. The time element was also recorded and punched on the cards so that velocities of each point could be calculated by the formula: $\text{velocity} = \text{distance}/\text{time}$. By simply measuring the displacement of distance covered between selected frames and dividing by the time elapsed between these frames, any velocity could be calculated.

When the data was returned from the computer center the path of the center of gravity was plotted for each subject. This allowed the researcher to see at what point it leveled out, in other words, at what point the sprinter had discontinued her drive and was in her running position.

Angles. Any pertinent angle, such as angle of drive, knee angles and angle of hip elevation could be calculated by plotting the relevant points and measuring the angle with a protractor. In some instances, only two points were plotted and the resultant straight line was compared to a known horizontal or vertical to measure the angle.

In this study, angle of drive was calculated by plotting the line of thrust through the toe and the center of gravity and comparing it to a known horizontal. The frame used for this computation on the first five subjects, all of which used a crouch start, was the analyzed frame immediately preceeding the first foot strike. For the sixth subject, who used a standing start, the analyzed frame that was two frames before foot strike was used. In all subjects, this was the nearest analyzed frame where the front foot had just left the block and the rear leg was in complete extension.

The angle of knee flexion in the set position was considered an important facet of the start. This angle was determined by plotting the joint centers of the hip, knee and ankle and measuring this angle with a protractor. The angle of knee flexion is affected by the distance of the feet from the line, the height of the hips and the forward lean over the line.

Distances. Distances were obtained either by actual measurement before filming or by measuring distances on the film and applying the multiplier. In some cases, it was easier to compute distances by simply subtracting certain coordinates from another and applying the multiplier.

The spacing of the feet was obtained at the time of filming. The subjects placed the blocks at distances suited to their own preference. The distance of each foot from the starting line was measured and the distance between the two of them computed by simply subtracting these two measures.

The amount of forward lean was obtained by using the x coordinates for the left hand, and the left shoulder. The difference between

these two joints was calculated and the multiplier applied to change the result to inches. The amount of hip elevation above the shoulders was found in a similar manner. The y coordinates for the left hip and left shoulder were obtained, the difference calculated and the multiplier applied to change it to life size.

Time. Time was an important aspect for figuring velocities and response time. It was calculated from the film speed of the camera. For this study, the camera was filming at 200 frames per second which means there is 1/200th second between each frame. In the section of analysis that involved analyzing every tenth frame, the time factor between analyzed frames was reduced to 0.05 seconds. In the portion where every twentieth frame was analyzed, the time factor changed to 0.10 second. In additional analyzed frames, such as foot strike, the time was calculated by dividing the number of frames by the filming rate.

Time was reinforced by the use of the time clock placed in the filming area. On each analyzed frame, cumulative time was read from the clock and placed on the data sheet. In cases of discrepancies, the camera time was considered more accurate than the clock and this calculated time was used.

Response time to the film was figured from gun flash to the frame where the rear foot cleared the blocks. This amount of time was used because it was a comparable movement to the one used to test response time in the laboratory. This response time was then compared to the laboratory response time and the Pearson-Product Moment Correlation used to see if a correlation existed between them. Additional correlations were run between all variables by use of the computer center.

SUMMARY

Six members of the Kansas State University women's track team volunteered as subjects for this study. All subjects were tested on leg strength and response time and then filmed with high speed cinematography performing the sprint start. Three good trials were filmed and the best trial was used for analyzation. The film was analyzed using a Lafayette Analyzer, a Craig Editor Splicer and a Recordak film reader. The data obtained from this analysis was used to find the center of gravity and velocities by means of the Wildcat Computer Program. Other variables were also taken from the film such as angles, distances and time.

Chapter 4

RESULTS AND DISCUSSION

The problem of this study was to determine the relative importance of selected variables upon the efficiency of a sprint start as performed by female athletes. The purpose of the study was to analyze the sprint start by use of cinematography, leg strength tests and response time tests. The results of the study were divided into two main sections: analysis of results and discussion of results.

ANALYSIS OF RESULTS

This section contains all results found on leg strength, response time, and form. The division of form was further subdivided to include center of gravity, knee flexion, forward lean over the line, angle of drive, height of the hips, spacing of the feet and velocity.

Leg Strength

In the leg strength testing, each subject was allowed two trials, with the best effort recorded as the subjects leg strength. Table 1 contains each subjects maximum leg strength in relation to their order of finish.

Variation between subjects was minimal with a range of only 40 pounds found among all six subjects. However, great variation was found in certain subjects from their first and second trial with maximum variation being 130 pounds. This would indicate to the researcher that this particular leg strength apparatus was subject to learning and

as the subject was allowed more trials she would continue to improve up to a point.

Table 1
Leg Strength in Relation to Order of Finish

Subject	Maximum Leg Strength in Pounds	Order of Finish
1	290	3
2	280	5
3	300	1
4	290	6
5	280	4
6	260	2
Mean = 283.3	Range = 40	Standard Deviation = 13.7

Note that the subject who finished first (Subject 3) recorded the greatest leg strength. However, no subsequent relationship can be found with the remaining subjects as a correlation of $r_{xy} = 0$ was found.

Response Time

Two response time measures were taken, one in a laboratory situation and one from the film in response to the gun. The Pearson Product Moment Correlation (r) was run on the two groups of data and an $r_{xy} = 0$ was found indicating that the groups of data were uncorrelated. Table 2 shows both sets of response time data in relation to the order of finish. Correlations were also run between film response time and order of finish ($r_{xy} = .090$) and laboratory response time and order of finish

($r_{xy} = .464$) both insignificant at the .05 level.

One factor that can affect the magnitude of product-moment correlations is the range of scores for the variables. A narrow range tends to reduce r . In this study the range for laboratory response time was only 0.08 seconds and for film response time was only 0.16 seconds. This may have had an affect on the calculated r .

Table 2
Response Time in Relation to Order of Finish

Subject	Laboratory Response Time in seconds	Film Response Time in seconds	Order of Finish
1	0.180	0.305	3
2	0.250	0.195	5
3	0.230	0.240	1
4	0.260	0.355	6
5	0.250	0.300	4
6	0.240	0.351	2
Mean	0.235	0.291	
Range	0.080	0.160	
S.D.	0.029	0.063	

Subject 1 ranked first in laboratory response time but fell to fourth in film response time. Subject 2 was first in film response time and ranked fifth in laboratory response time. Note that there was a much closer range in the laboratory response time. Subjects three was found to rank second in both response time tests. It should be

noted that simple observation of when the foot leaves the blocks does not take into account the fact that a subject may have already reacted and is using the time to produce force on the blocks by driving backwards before picking the foot off the blocks. Therefore, without knowing or taking into account this force being produced on the blocks, it is not reasonable to assume that picking the foot up quickly is the most desirable method of starting. However, with all things being equal (such as force on the blocks), a faster response time would get the sprinter off the blocks and started down the track in the shortest length of time. It was not possible to determine this aspect in this study because no force recordings from the blocks were taken.

Form of the Start

The form of the start involves those things that are manipulated by the sprinter in an attempt to achieve a more effective start. Many of these variables are interrelated and a change in one produces a change in another. The results of each variable were presented and discussed separately.

Path of the center of gravity. The center of gravity is the theoretical center of weight of an object or person. "The center of gravity of a body does not remain in a fixed position. Rather, the center of gravity will change within a body depending on the motion of that body." (39:36). Figure 2 is a pictorial drawing of Subject 3 performing her start. The center of gravity paths of all subjects were not included as they were all very similar but rather only two were showed for the sake of comparison. A separate time scale is included for the path of each

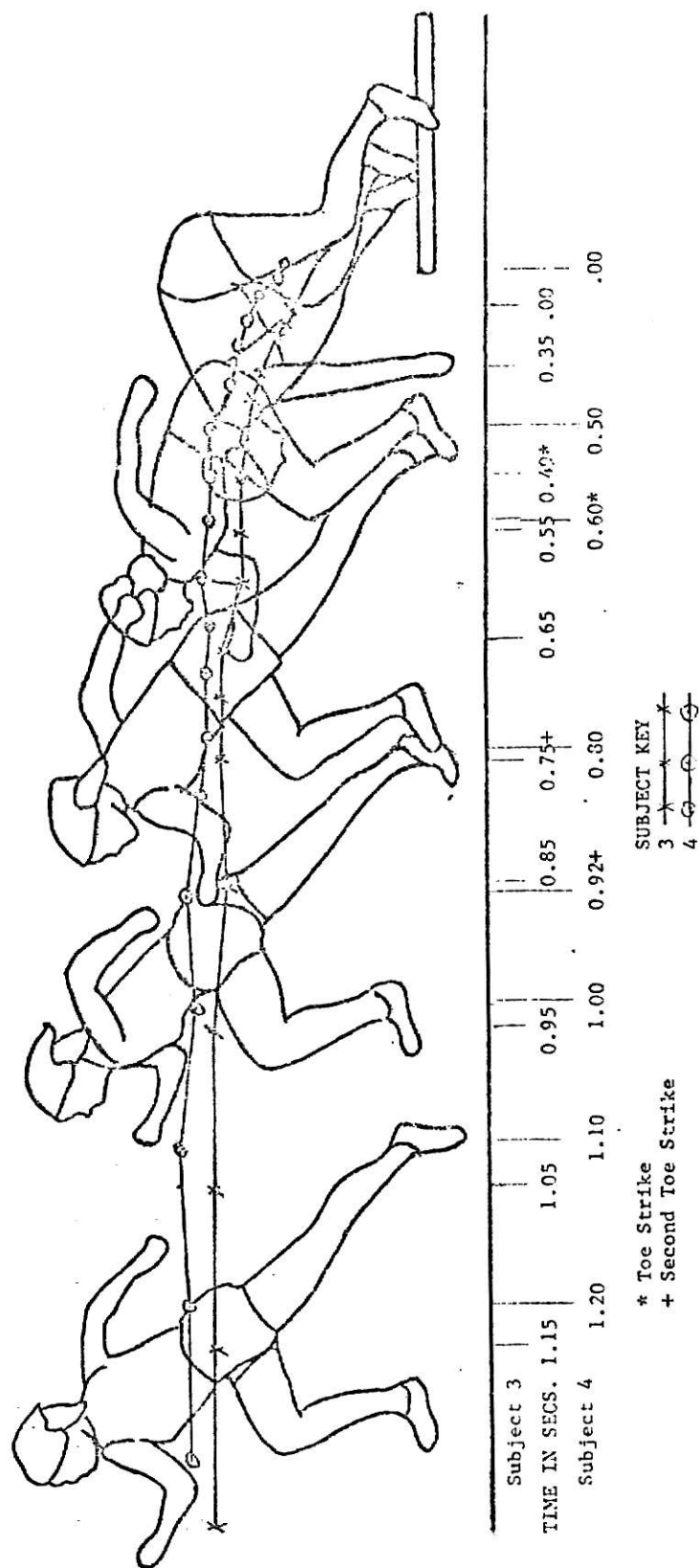


Figure 2: Outline of the body of Subject 3 and a comparison of center of gravity paths between Subjects 3 and 4.

subject's center of gravity for a comparison of elapsed time at certain points, such as toe strike. There was a constant time between frames. Note that on Subject 3 both foot strikes occurred before Subject 4. Research states that for maximum acceleration, the starter should take small steps at first and gradually increase her stride, since the runner is only accelerating when her feet are pushing against the ground. Note also the levelness of the center of gravity path for Subject 3. This would indicate that she was not wasting energy or motion by running up and down but rather was running smoothly once in running position. There was a fairly gradual and steady slope to the path at the beginning of the start indicating that she had a good set position, allowing her to drive directly in the desired direction at a beneficial angle.

The vertical position of the center of gravity of each subject is listed in Table 3. The range of vertical movement is also shown. The range was computed from the second toe strike to the maximum height of the center of gravity throughout the start.

Table 3
Position and Range in Vertical Movement of Center of Gravity

Subject	Set Position in inches	Toe Strike in inches	Second Toe Strike in inches	Range in inches
1	1.494	1.882	2.051	.169
2	1.409	1.892	1.996	.104
3	1.395	1.912	1.978	.066
4	1.427	2.165	2.253	.088
5	1.390	1.957	2.046	.089
6	1.613	2.068	2.171	.103

Subject 3 again has the least variation. Even Subject 6 who utilized a standing start had a large range.

The results suggest that a steady incline at the beginning with a smooth center of gravity path once running position is attained is the most desirable. Subject 3 seemed to exhibit these qualities in her start.

Knee flexion. The degree of flexion in the rear knee is related to other aspects of the start such as height of the hips, distance of the feet from the line, forward lean over the line and is subject to change if any of these are altered. Most of the subjects had not been instructed in effective starting techniques and the knees were flexed to a relatively small angle when referring to sprint starts. Table 4 shows variation in these angles in relation to their order of finish.

Table 4

Rear Knee Angle, Forward Lean and Height of Hips
in Relation to Order of Finish

Subject	Rear Knee Angle in degrees	Forward Lean in inches	Height of Hips in inches	Order of Finish
1	96.0	3.57	8.03	3
2	112.5	2.57	5.99	5
3	121.0	2.99	4.28	1
4	88.0	-.86	5.14	6
5	100.0	4.29	4.29	4
6	83.0	---	---	2
Mean	100.1	3.11	5.55	
Range	38.0	6.85	3.75	
S.D.	14.38	2.55	1.56	

Note that the subject with the greatest angle (Subject 3) finished first and the subject with the smallest angle (Subject 4) finished last. Note also the small angle utilized by Subject 6 who performed a standing start. Knee flexion is used to lower the center of gravity so that she may effectively drive once the gun has been fired. It should be noted that in the standing start, the rear knee angle is usually much smaller than the front knee angle. In this subject the front knee angle was 108 degrees. In the crouch start, depending on the distance between the feet, the angles are much more similar between knees. The range between subjects (not including Subject 6 who used a standing start) was 33 degrees.

The results would suggest that a larger rear knee angle is recommended for an efficient start. Possibly, more effective drive can be obtained with the leg in a slightly more extended position.

Forward lean over the line. The principle of motion for quick movement in one direction dictates that the performer should have the center of gravity close to the edge of the base of support in that direction. By leaning forward over the hands, the sprinter is accomplishing this objective. Once the hands are picked up off of the track, the sprinter will be off balance and will be forced to drive the legs quickly and powerfully up and underneath her to prevent stumbling and falling.

Table 4 also contains a comparison of forward lean between the subjects. Except for places 3 and 4 in order of finish which are interchanged (second place is disregarded because of the standing start) there is a definite relation between lean over the line and order of finish. Subject 3 exhibits the greatest amount of forward lean and was ranked first in order of finish. Note that Subject 4 did not lean

over the line and in fact was slightly backwards. This would suggest that she had rocked back over her legs and had her center of gravity more centered over her base of support which would slow the movement in the desired direction. This was supported by the fact that she finished last of the six performers. Rocking forward over the hand seems to be a desirable variable for efficiency in sprint starting.

Height of the hips. As stated previously, the height of the hips is affected by other variables such as distance of the feet from the line, forward lean over the line and rear knee angle. If the hips are extremely high in the air, it causes the body's center of gravity to travel up and down at takeoff. This was very noticeable in the center of gravity paths of Subjects 1 and 2 which are available in Appendix F.

Refer again to Table 4 for a comparison of the height of hips between subjects. There was a range of 3.75 inches in this study which could partially be due to the length of the subjects legs. There was a maximum difference in leg length of $2\frac{1}{2}$ inches between all subjects. The best performer had her hips raised the least. However, no correlation was found between height of hips and order of finish. Perhaps the height of the hips is more of a byproduct of the other variables and does not have an affect on the start in and of itself.

Angle of drive. The angle of drive was calculated by drawing a line through the toe and the center of gravity at a selected frame prior to the first foot strike and comparing this to a known horizontal. This aspect is important because if a sprinter has an extremely large angle of drive, it could indicate that she is standing up too quickly and not

taking advantage of the full drive out of the legs in the desired direction. Table 5 shows the angle of drive for all subjects and their order of finish.

Table 5
Angle of Drive in Relation to Order of Finish

Subject	Angle of Drive in degrees	Order of Finish
1	39	3
2	38	5
3	38	1
4	40	6
5	38	4
6	44	2
Mean = 39.5	Range = 6.0	S.D. = 2.35

Note how much larger the angle is for the standing start compared to the crouch start. This was because Subject 6 was already much closer to running form and possibly if the angle of drive had been calculated near the second foot strike, the crouch start angle would have been closer to the standing start. Note also that the other five starters varied only two degrees in their angle of drive, again leaving little room for comparison and conclusions. However, on the basis of this study, it is concluded that 38-40 degrees is a desirable takeoff angle.

Spacing of the feet. By definition, in the bunch start the toe of the back foot is opposite the heel of the front foot while standing. Using

that definition all subjects would be using a bunch start. The range between subjects was only three inches as shown in Table 6.

Table 6
Distance Between Feet in Relation to Order of Finish

Subject	Distance Between Feet in inches	Order of Finish
1	9.00	3
2	9.00	5
3	6.00	1
4	7.00	6
5	7.00	4
6	8.75	2
Mean = 7.79	Range = 3.00	S.D. = 1.29

Since the subjects had too close of a range in footspacing no conclusions can be drawn on this variable. Either many more subjects would have to be tested or these subjects manipulated to attempt a variety of other types of starts to be able to compare and draw conclusions.

The researcher would like to suggest that the type of start, either bunch, medium or elongated, be defined in relation to the distance between the feet and the hands, rather than the distance between the feet. For example, a sprinter could be extremely spread out between his hands and feet but be considered in a bunch start position if his feet were close together. This then would make the term refer to the whole body position in the start and not just one aspect, the feet.

Velocity. It is desirable in the sprints to be going fast as soon as possible. In this study, the subjects were still accelerating and were not near top speed at the point where analysis stopped. Most researchers claim that a runner reaches top speed around 60 yards. However, if a runner reaches top speed sooner, obviously she will have more time in the race to be running at top speed.

Table 7 contains the maximum velocity obtained by each subject in this study. This velocity was obtained within a distance of 15 feet from the starting line.

Table 7

Maximum Velocity in 15 Feet in Relation to Order of Finish

Subject	Maximum Velocity ft./sec.	Order of Finish
1	17.23	3
2	17.23	5
3	17.64	1
4	16.96	6
5	17.50	4
6	17.39	2
Mean = 17.33	Range = 0.68	S.D. = 0.24

Subject 3 had the highest maximum velocity during the start in this study and finished first. The last place finisher had the slowest maximum velocity in her start.

Velocity equals distance divided by time. Therefore over a certain distance, such as a 100 yard dash, a higher velocity would

result in a shorter period of elapsed time which is the object of the race. The greater the velocity and the sooner it is reached, the more advantage the runner would have.

DISCUSSION OF RESULTS

Because this study involved such a small sample size, it was difficult to draw definite conclusions. However, it was interesting to note that the subject who finished first by time also ranked first in nearly all of the other variables, especially all of those believed to be important. Also, those variables selected as possibly having an effect on the start exhibited a close rank order correlation according to order of finish.

Table 8 is a composite table of all the variables so that the reader may compare each subject on all variables. The mean, range and standard deviation of each variable is also provided. Table 9 contains correlations run between all variables. Rear knee angle and film response time, velocity and forward lean are the only two correlations that were significant at the .05 level.

Most of the literature reviewed seemed to indicate that increased leg strength could have a positive effect on starting time and force. In this particular study, leg strength did not seem to be a contributing factor. However, it appears that the testing did not measure what it was supposed to measure, thus there may or may not be a direct correlation. The testing equipment was assumed to be adequate as it was used in the Physiology of Exercise Laboratory at Kansas State University to test leg strength on all freshman students. It was not until the testing was complete and the data accumulated that the researcher found

Table 8
Variable Comparison

Subject	Distance Between Feet inches	Leg Strength pounds	Response Time (lab) seconds	Response Time (film) seconds	Rear Knee Angle degrees	Height of Hips inches	Forward Lean inches	Angle of Drive degrees	Maximum Velocity ft./sec.	Order of Finish
1	9.00	290	.180	.305	96.0	8.03	3.57	39	17.23	3
2	9.00	280	.250	.195	112.5	5.99	2.57	38	17.23	5
3	6.00	300	.230	.240	121.0	4.28	5.99	38	17.64	1
4	7.00	290	.260	.355	88.0	5.14	-.86	40	16.96	6
5	7.00	280	.250	.300	100.0	4.29	4.29	38	17.50	4
6	8.75	260	.240	.350	83.0	---	---	44	17.39	2
Mean	7.79	283.3	.235	.291	100.1	5.55	3.11	39.5	17.33	
Range	3.00	40.0	.080	.160	38.0	3.75	6.85	6.0	.68	
Standard Deviation	1.29	13.7	.029	.063	14.38	1.56	2.55	2.35	.24	

Table 9
Variable Correlations

	Distance Between Feet inches	Leg Strength pounds	Response Time (lab) seconds	Response Time (film) seconds	Rear Knee Angle degrees	Height of Hips inches	Forward Lean inches	Angle of Drive degrees	Maximum Velocity ft./sec.	Order of Finish
Distance Between Feet	1.00**									
Leg Strength	-0.58	1.00**								
Response Time (lab)	-0.36	-0.25	1.00**							
Response Time (film)	-0.02	-0.33	0.01	1.00**						
Rear Knee Angle	-0.38	0.61	-0.04	-0.90*(.898)	1.00**					
Height of Hips	0.85	-0.09	-0.76	0.05	-0.32	1.00**				
Forward Lean	-0.22	0.26	-0.40	-0.52	0.75	-0.16	1.00**			
Angle of Drive	0.36	-0.75	0.07	0.68	-0.77	0.30	-0.82	1.00**		
Maximum Velocity	-0.38	0.02	-0.11	-0.35	0.53	-0.45	0.95*	-0.16	1.00**	
Order of Finish	0.16	-0.00	0.46	0.09	-0.28	0.08	-0.90(.896)	-0.21	-0.81	1.00**

* Significant at 0.05 level

**Significant at 0.01 level

that the equipment was inadequate for this study because of the influence of grip strength on the test. A hip belt method would have been more appropriate. Therefore, the data obtained from this study concerning leg strength is of questionable value. The researcher believes that it could be an important factor as it would provide more power and force available to drive against the blocks. A similar study with more subjects and more intensive testing might produce a positive correlation. Also, a different device for testing leg strength would be desirable.

No correlation was found between either the laboratory response time and the film response time or the order of finish and either set of response time data. As was mentioned in the literature, it was concluded that response time could have an effect on the start in beginners, but once the sprinter has learned the skill, response time has less and less of an effect on the sprint start. The mean film response time (block clearance) found in this study was 0.291 which is an acceptable range to the figure found in the literature of 0.244 for a 10.5 inch bunch start. All six subjects in this study used a bunch start. However, the foot-spacing was less than 10.5 inches because of the difference between men's and women's sizes. It should be remembered that the data obtained from the literature was on male subjects who are highly skilled. On the majority, females have been exposed to less training which could account for the higher response time. Another item of importance to remember when comparing the response time data between the film and the laboratory is what had to be moved. In the laboratory, just a foot was moved. In the actual start taken from the film, in order for the foot to move, the whole body had to be moved. The greater amount of force being used

required more time.

The path of the center of gravity can be an indication of certain problems or mistakes being made in the start. For example, it could show if the sprinter is standing up too fast and not getting the proper angle of drive. If the path of the center of gravity travels up and down at takeoff it could indicate that the hips are too high in the set position.

In reference to rear knee angle, a medium range of knee flexion between 110 and 125 degrees was found most effective in the literature. It was affected by the footspacing and height of the hips. Two subjects in this study had knee angles within this range and the mean was 100.1 degrees. This figure was slightly reduced because of the small rear knee angle used by Subject 6 in her standing start. If her angle was not included, the mean figure would be 103.5, still not within this range. The two subjects that did fall within this range had been coached at the college level and finished first and fifth in this study.

Researchers claim that the hips should be slightly higher than the shoulders and the sprinters should lean approximately 6 to 8 inches (for males) over the line to get the center of gravity closer to the line. As "slightly higher" is rather vague, the researcher believes that 4 to 6 inches would be sufficient and 4 of the 5 subjects affected by this variable would fit in this range. One subject had her hips 8.03 inches above her shoulders but could have been caused by her longer legs. As for the lean over the line, it must be remembered that the figure from the literature was taken on males and because of the females shorter trunk length, a smaller amount would indicate a proportional amount of lean. The range of forward lean in this study was from -0.86 to 5.99

inches, the mean being 3.11 inches. If a range of approximately 4 to 6 inches for females was used as desirable, 2 of the 5 involved subjects would fall in this range.

It was anticipated that the angle of drive would be much more varied due to the many other variables under use and observation. Since no exact angle was found in the literature, it was assumed that possibly an angle of drive between 38 and 40 degrees as was found in this study to be a natural and beneficial angle for the sprint start.

Again, spacing of the feet showed a very small range in this study. In relation to both force and quickness, a medium start was considered the best in the literature review. For males, the footspacing for a medium start would be approximately 16 to 21 inches. For females, this would be approximately 4 inches shorter due to leg length, bringing it to 12 to 17 inches. No one in this study fell within this range as all subjects chose to use a bunch start.

The research currently done on the standing start promotes it as a very efficient starting technique. The subject in this study using a standing start finished second yet did not rank extremely high in any of the specific variables. More research is definately needed in this area.

With so many factors available to influence the efficiency of the start, it is quite possible for a sprinter to compensate for a weakness or an error with a strength in another aspect. For example, a sprinter with a poor response time would compensate for this by having tremendous leg strength and power or excellent mechanical technique. This is one reason it was difficult to measure all of the variables in one trial with complete accuracy.

SUMMARY

The following is a summary of the findings in this investigation:

1. Leg strength was not a contributing factor to the sprint start. However, inadequate testing equipment could have been a determining factor in the leg strength test results.
2. No correlation was found between either laboratory response time and film response time or the order of finish and either set of response time data.
3. Rear knee angle was found to be an important variable in sprint starting. The subject with the greatest angle in this study finished first and the subject with the smallest angle (excluding the standing start) finished last.
4. Four of the five subjects affected by height of the hips had hips between 4 to 6 inches above the shoulders. This was considered to abide by current research.
5. The range of forward lean between subjects was quite large. Two of the five subjects affected by this variable had a desirable amount of forward lean according to the literature.
6. In this study, angle of drive ranged between 38 and 40 degrees for the subjects using a crouch start. It was assumed that this was a natural and beneficial angle for the sprint start.
7. Footspacing in this study ranged between 6 and 9 inches and was designated as a bunch start in all subjects. The literature claims that the medium start is the best but because no subjects used a medium start, no comparisons could be drawn.
8. The standing start was found to be an effective starting

technique in relation to order of finish. Subject 6 utilized a standing start and finished second among all subjects. More research needs to be done in this area.

Chapter 5

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

A summary of this study is presented including the problem, the purpose and the basic procedures followed. The author then stated the findings obtained, the conclusions drawn and recommendations for further study.

SUMMARY

The Problem

The problem of the study was to determine the relative effect of selected variables upon the efficiency of a sprint start as performed by female athletes.

Purpose of the Study

The purpose of the study was to analyze the sprint start of six female performers by use of cinematography, leg strength tests and response time tests. An attempt was made to integrate these variables with those taken from the cinematographical analysis, for example: knee flexion, angle of drive, forward lean over the line, height of the hips, spacing of the feet, velocity and response time to the gun. It was of interest to the researcher to determine which variables were important and must be emphasized or corrected while coaching the young sprinter and those which were unimportant and could be disregarded.

Prodecures

Six experienced females from the Kansas State University track

team volunteered as subjects for this study. All subjects were measured and marked with pieces of white tape at pertinent joint centers for ease in analyzation of the film.

Each subject was tested on leg strength with a leg strength dynamometer and on response time with a Dekan Timer Model 631. To film the subjects performance of the sprint start, a 51-002 Redlake Locam 16mm camera equipped with a 25mm lens was used. Filming was done at 200 frames per second and three good trials were taken of each subject.

Analysis of the film included path of the center of gravity, angles, distances and time. A horizontal and vertical coordinate system was used to locate joint centers. These coordinates were then used to find the path of the center of gravity by means of the Wildcat Computer Program. Every tenth frame was analyzed until the second foot strike, and every twentieth frame was analyzed from the second foot strike until the subjects crossed a tape mark placed on the track.

FINDINGS

The following is a summary of the findings in this investigation:

1. Leg strength was not a contributing factor to the sprint start. However, inadequate testing equipment could have been a determining factor in the leg strength test results.

2. No correlation was found between either laboratory response time and film response time or the order of finish and either set of response time data.

3. Rear knee angle was found to be an important variable in sprint starting. The subject with the greatest angle in this study

finished first and the subject with the smallest angle (excluding the standing start) finished last.

4. Four of the five subjects affected by height of the hips had the hips between 4 to 6 inches above the shoulders. This was considered to abide by current research.

5. The range of forward lean between subjects was quite large. Two of the five subjects affected by this variable had a desirable amount of forward lean according to the literature.

6. In this study, angle of drive ranged between 38 and 40 degrees for the subjects using a crouch start. It was assumed that this was a natural and beneficial angle for the sprint start.

7. Footspacing in this study ranged between 6 and 9 inches and was designated as a bunch start in all subjects. The literature claims that the medium start is the best but because no subjects used a medium start, no comparisons could be drawn.

8. The standing start was found to be an effective starting technique in relation to order of finish. Subject 6 utilized a standing start and finished second among all subjects. More research needs to be done in this area.

CONCLUSIONS

Within the limitations of this study the following conclusions were drawn from the data analyzed. It should be remembered that only six average track performers were filmed prior to the track season and this could have biased the results.

1. Leg strength and response time did not significantly affect

the ability to start efficiently. These results may have been altered due to inadequate testing equipment for leg strength.

2. On the basis of this study, rear knee angle, forward lean over the line, and velocity were factors that contributed to the efficiency of the start and should be emphasized when coaching the young sprinter. Spacing of the feet and angle of drive could also have been important but too small of a range was obtained to draw a definite conclusion.

RECOMMENDATIONS

The following recommendations are presented for further research. They are based on the results and conclusions of this study.

1. Utilization of more subjects would improve the validity of comparison and conclusions.

2. Leg strength testing involving either a training session so as to get an accurate maximum reading and avoid the learning during trials or use of a hip belt rather than the hand grip to avoid having grip strength as an influence on the leg strength.

3. Triaxial cinematography, a force platform and response time equipment on the blocks would allow for greater accuracy in both findings and conclusions.

4. Allowing the subjects to run to a point farther down the track with an accurate timing device at this point would possibly show the effect of the entire start.

5. Using the same subjects with a controlled variation in the variables would exhibit the real strength of that variable and not just

how well each subject mastered a certain variable.

6. Investigation of the difference in starting techniques between men and women could confirm the importance of selected factors in the start.

7. More research on the efficiency of the standing start is needed as current research claims it has many advantages.

8. An instruction period or filming later during the track season would result in more refined starting techniques. Filming during actual competition would yield better starts as a result of motivation and excitement.

9. Use of national or world caliber athletes would produce more accurate results.

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REFERENCES

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APPENDICES

APPENDIX A

THE SEGMENTAL METHOD AS
REPORTED BY WALLACE
(39:64-65)

The segmental method is a method used to determine the center of gravity of a total body, especially when that body is in motion. To use the segmental method, the following information is needed: the percentage of the total body weight of each segment; the location of the center of gravity of each segment; the horizontal distance of each center of gravity from a vertical line; and, the vertical distance of each center of gravity from a horizontal line. (8:172)

Each body segment was defined as listed below:

Trunk- The top of the sternum to the crotch.

Head and Neck - The tragus of the ear to top of the sternum.

Right Thigh - The greater trochanter of the right femur to the lateral condyle of the tibia.

Right Lower Leg - Lateral condyle of the tibia to the lateral malleolus of the fibula.

Right Foot- The lateral malleolus of the fibula to the end of the great toe of the right foot.

Left Thigh- The greater trochanter of the left femur to the lateral condyle of the tibia.

Left Lower Leg - The lateral condyle of the left tibia to the lateral malleolus of the left fibula.

Left Foot - The lateral malleolus of the left fibula to the end of the great toe of the left foot.

Right Upper Arm - The acromion process of the right scapula to the lateral epicondyle of the humerus.

Right Lower Arm - The lateral epicondyle of the right humerus to the styloid process of the right ulna.

Right Hand - The styloid process of the right ulna to the tip of the middle finger.

Left Upper Arm - The acromion process of the left scapula to the lateral epicondyle of the humerus.

Left Lower Arm - The lateral epicondyle of the left humerus to the styloid process of the left ulna.

Left Hand - The styloid process of the left ulna to the tip of the middle finger of the left hand.

Given next is a list of the body segments, the percentage of the segment that its center of gravity is located in, and the proportion that the segment contributes to the total body weight.

<u>Body Segment</u>	<u>% Segment</u>	<u>Prop. Body Weight</u>
Trunk	0.4500	0.5140
Head and Neck	0.5000	0.0790
Right Thigh	0.4330	0.0965
Right Lower Leg	0.4330	0.0450
Right Foot	0.4290	0.0140
Left Thigh	0.4330	0.0965
Left Lower Leg	0.4330	0.0450
Left Foot	0.4290	0.0140
Right Upper Arm	0.4360	0.0265
Right Lower Arm	0.4300	0.0155
Right Hand	0.5060	0.0060
Left Upper Arm	0.4360	0.0265
Left Lower Arm	0.4300	0.0155
Left Hand	0.5060	0.0060

By knowing the X-Y coordinates of each segment, the center of gravity of the total body can be located. To find the X-coordinate, the proximal X-coordinate of the segment is subtracted from the distal X-coordinate. This difference is then multiplied by the percent of the segment. This product is added back to the proximal X-coordinate for the center of gravity of the segment. Then to find the center of gravity of the total body, each X-coordinate for the center of gravity of the segment is multiplied by its proportion of body weight and then all of these segment products are added together to yield the X-coordinate of the center of gravity for the total body. The same procedure is followed to obtain the Y-coordinate of the center of gravity of the total body.

APPENDIX B

SUBJECT DATA SHEET

Subject Number _____ Skill filmed _____

Name _____ Address _____ Phone _____

Age _____ Height _____ Weight _____

Skill classification _____

Joint Markings (Indicate plane and side) _____

Anatomical Measurements

upper leg upper arm thigh(8" from hip)

lower leg lower arm calf(5" from knee)

shoe size _____

Measurements of starting position

front foot from line _____ l. r.

rear foot from line _____ l. r.

Measurement unit _____

Leg Strength

Trials _____

Response Time Test Results

Trial:	1	6	11	Mean _____
	2	7	12	
	3	8	13	
	4	9	14	
	5	10	15	

*denotes measurement unit

APPENDIX C
INFORMED CONSENT FORM

As indicated by my signature below and being of sound mind, I do hereby voluntarily consent to serve as a subject in the proposed procedure identified and explained in the document dated 9/20/75 and entitled "The Effects of Selected Variables Upon an Efficient Sprint Start" which document is attached to and is hereby made a part of this consent.

Subject Name	Age	Subject Signature	Date
1. _____	_____	_____	_____
2. _____	_____	_____	_____
3. _____	_____	_____	_____
4. _____	_____	_____	_____
5. _____	_____	_____	_____
6. _____	_____	_____	_____
7. _____	_____	_____	_____
8. _____	_____	_____	_____
9. _____	_____	_____	_____
10. _____	_____	_____	_____

Witnessed by:

* Subjects agree to allow films of start to persons other than the researcher in an effort to help future runners better learn the start.

RIGHTS AND WELFARE OF HUMAN SUBJECTS

"The Effects of Selected Variables Upon An
Efficient Sprint Start"

Read the information on this sheet and if you wish to be a participant in this study fill in the information on the following page entitled "Informed Subject Consent".

Purpose

The purpose of the study was to attempt to determine what aspects of a sprint start significantly affect its efficiency.

Procedures

The subjects for the research were six female sprinters from the Kansas State University track team. Each subject was filmed in the sagittal plane with precise measurements taken on foot placement from the starting line. There were three trials filmed of each subject. Subsequent tests involved leg strength utilizing a leg strength dynamometer, response time by using a Dekan Timer and foot pad, and a measurement of leg length in inches. All subjects were taped at the joint centers for ease in analysis.

Risks

There are no risks involved in this research other than those normally involved with track workouts. Any injury or emergency will be handled through normal University policy.

Alternative Procedures

There are alternative procedures of gross observations, still photographs, but both are inferior to motion picture filming in gaining benefits for analysis. The risks are the same for all methods.

Benefits

The basic benefit derived from participating in this study is a better understanding of technique involved in the sprint start.

Questions and Inquiries

Any questions that the subjects may have about the research or filming or testing procedures will be answered as completely as possible by the researcher.

Withdrawing from the Study

Subjects are free to withdraw from this study at any time if they feel they would rather not participate in this research.

APPENDIX D

LEG STRENGTH TEST INSTRUCTIONS

1. Subjects legs are bent to an angle of approximately 120 degrees.
2. The back is to remain straight so as to prevent back injury.
3. The bar is to be grasped with a mixed grip (one hand forward and one hand back).
4. Arms are to hang straight down and no pull is made with the arms.
5. Subject will attempt to straighten the legs against the resistance presented by the dynamometer.
6. Two trials will be recorded and the best score will be counted as the subjects leg strength.

APPENDIX E

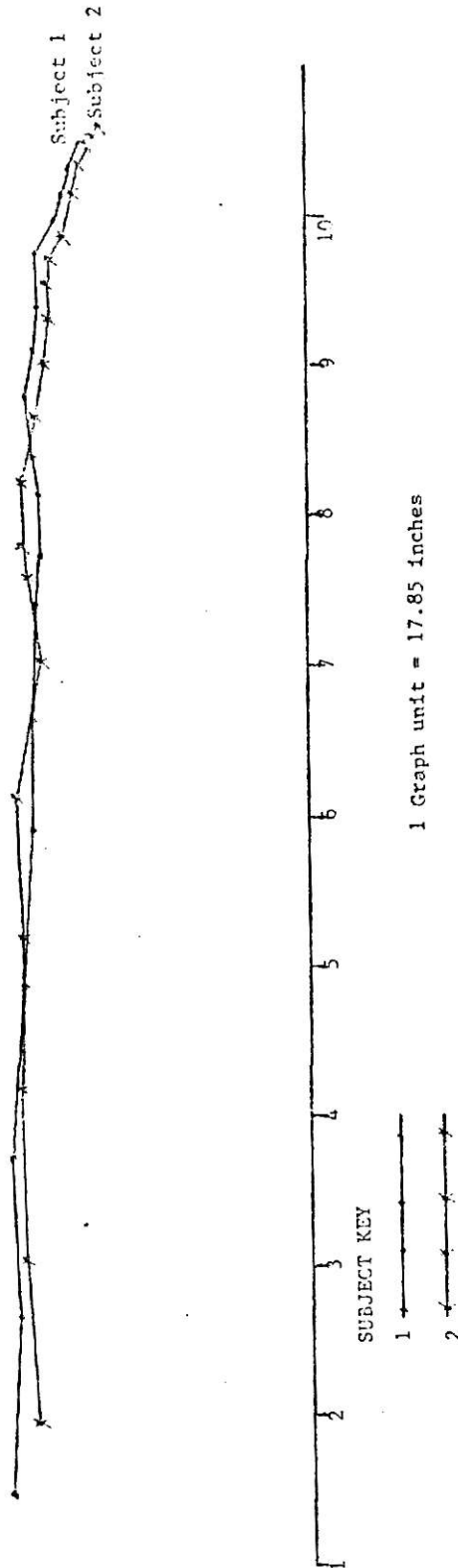
RESPONSE TIME TESTING INSTRUCTIONS

1. Subject will stand with "S" foot beside the mark placed 4 inches from the edge of the Dekan timer foot pad.
2. The "T" foot will be placed in the center of the foot pad.
3. Weight is to be evenly distributed on both feet.
4. The subject will be given a preparatory signal "ready" 1-4 seconds before the stimulus buzzer. This foreperiod is variable.
5. At the sound of the buzzer, the subject is to raise her "T" foot off the mat as quickly as possible, breaking contact in the circuit.
6. The subject will be given 5 practice trials.
7. Fifteen actual trials will be recorded after the practice trials.

* These tests will be taken with the foot that is in the rear block.

(It is denoted as "T". The foot that does not move is denoted as "S".)

APPENDIX F



PATH OF THE CENTER OF GRAVITY FOR SUBJECTS 1 AND 2

THE EFFECT OF SELECTED VARIABLES
UPON AN EFFICIENT SPRINT START

by

PAMELA S. PEARSON

B.S. Kansas State University, 1975

AN ABTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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1976

ABSTRACT

The purpose of this study was to analyze the sprint start of six female performers by use of cinematography, leg strength tests and response time tests. An attempt was made to integrate these variables with those taken from the cinematographical analysis, for example: knee flexion, angle of drive, forward lean over the line, height of the hips, spacing of the feet, velocity and response time to the gun. It was of interest to the researcher to determine which variables were important and must be emphasized or corrected while coaching the young sprinter and those which were unimportant and could be disregarded. Six experienced females from the Kansas State University track team volunteered as subjects for this study. Each subject was tested on leg strength and response time and filmed with high speed cinematography performing a sprint start. Three trials of each subject were filmed with the best trial used for analysis. The raw data was gathered by the use of a 16mm Recordak film reader, graph paper and a positive horizontal and vertical coordinate system. The path of the center of gravity was found from this data by means of the Wildcat Computer Program. Rear knee angle, forward lean over the line and velocity were concluded to be contributing factors to the sprint start. Spacing of the feet and angle of drive exhibited a range too close for comparison or definite conclusions. Leg strength testing equipment proved to be inefficient and thus the data obtained was of questionable value. Response time was not found to significantly affect the efficiency of the start in this study.