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A BIOMECHANICAL ANALYSIS OF THE SINGLE ARM VERSUS THE PARALLEL DOUBLE ARM TAKEOFFS IN THE TRIPLE JUMP

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A BIOMECHANICAL ANALYSIS OF THE SINGLE ARM VERSUS THE PARALLEL DOUBLE ARM TAKEOFFS IN THE TRIPLE JUMP

By

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ABSTRACT

A BIOMECHANICAL ANALYSIS OF THE SINGLE ARM VERSUS THE PARALLEL DOUBLE ARM TAKEOFFS IN THE TRIPLE JUMP

By

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Chairperson: Dr. V. Dianne Ulibarri

This dissertation investigated the effects of the single arm and double arm swing on triple jump performance. It also compared the performances of this study's novice triple jumpers to published findings for elite male triple jumpers. Seven female interscholastic track and field athletes who had had no previous training in the triple jump were used as subjects for this study. They were matched on their best long jump distance and then randomly assigned to either a single arm or a double arm group. Training methods were developed by the researcher in order to teach the subjects to triple jump using the assigned arm style.

Four LOCAM 16mm motion picture cameras were used to collect the data. Three cameras recorded a sagittal view of the performance while a fourth camera recorded a frontal view. The film images were digitized and these data were used in conjunction with a FORTRAN program to determine takeoff velocities and average support forces from the

sagittal views. Balance data for each support phase were obtained by manual techniques from the frontal view.

This study found that there was no statistically significant difference at the .10 level of significance between the single arm and double arm groups for any of the intervening variables under consideration with the exception of support times and horizontal takeoff forces. The findings for support times revealed that the hop and jump support times were similar for both groups. The double arm group's step duration, however, was considerably longer. This gave the double arm group greater horizontal and vertical impulses, an advantage during the most difficult step phase.

More notable was the statistically significant difference between phase distances ($F(2,6) = 49.44$, $p < .001$). The medium-short-long pattern used by all jumpers in this study resembled the Polish style. The subjects' mean jump distance, however, far exceeded any reported findings for elite Polish style triple jumpers. The novices may have resorted to the Polish style because they were not able to rebound from the stress of landing from a long hop. This may indicate that phase contributions may be a function of the jumper's strength, speed, and skill level.

To

my mother Theresa Rogers Larkins
and
my father Louis Larkins
who gave me the courage, determination,
and ability to complete this dissertation
and who taught me to believe in myself.

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INTRODUCTION

The Problem

The evolution of triple jump performance can be traced as far back as ancient Greece when athletes performed an event that required them to take off from the ground four or five times in succession (Bullard & Knuth, 1977). By the 19th century, it had evolved into an event with three phases in which the contestants executed a hop-hop-jump pattern (Tan, 1959; Bullard & Knuth, 1977). Bullard and Knuth (1977) also report that the present form of the triple jump (i.e., hop-step-jump) originated September 16, 1893, when Edwin Bloss of the United States officially jumped 48 feet 6 inches.

After Bloss's historic performance, coaches and athletes focused their attention on trying to discover the optimal contribution each phase should make to the total distance. At the turn of the century, jumpers viewed the triple jump as three separate jumps and emphasized the hop and jump phases to the detriment of the step phase. The Japanese, who emerged as a dominant force in triple jumping during the 1920's, placed most of their emphasis on the hop. Even though they tended to be small in stature and often lacked great speed, they nonetheless frequently hopped over 21 feet. They used this style of jumping to dominate three consecutive Olympic Games-- Mikio Oda in 1928, Chuhei Nambu in 1932, and N. Tajima in 1936. Their step phase was still rather short by today's standards, but they demonstrated that step distances of over fourteen feet could be used without detracting from the total distance (Doherty, 1976).

In 1935, Jack Metcalfe of Australia temporarily toppled the Japanese from their dominance when he established a world record of 51 feet 9 and 3/8 inches. In doing so he deviated from Japanese's long hop technique. His hop, step, and jump distances were 18 feet 6 inches, 13 feet 6 inches, and 20 feet 4 inches respectively, which clearly placed his emphasis on the jump phase. This technique of emphasizing the jump distance over the hop and step distance later became known as the Polish technique.

During the 1950's, Adhemar da Silva (Brazil) ushered in the balanced ratio philosophy of triple jumping. In 1950, he tied Tajima's world record with the greatest series of jumps up to that time, as the following statistics illustrate the balance of his phase distances (Doherty, 1976).

	HOP	STEP	JUMP	TOTAL
1.	18'8 3/4"	14'5 1/4"	16'4 7/8"	49'6 7/8"
2.	17'10 5/8"	15'2 5/8"	18'7/8"	51'2 1/8"
3.	17'8 1/4"	15'3"	18'2 1/2"	51'1 3/4"
4.	18'2 1/2"	15'6 1/4"	18'6"	52'2 3/4"
5.	18'2 1/2"	15'8 5/8"	18'7 5/8"	52'6 3/4"foul
6.	18'1 3/8"	15'10 1/2"	18'6"	52'5 7/8"

"The relative lengths of the hop, the step, and the jump warrant careful study for they are very similar to those of modern jumping. On a percentage basis, the three phases of his final record comprised 34.5--30.1--35.4 percent of the total effort, a very well-balanced performance, even by modern standards (Doherty, 1976, p. 185)."

da Silva went on to win the 1952 Olympic Games at Helsinki with a record breaking leap of 53 feet 2 and 1/2 inches; he established another world record in 1955 with a jump of 54 feet 4 inches; and finally, after coming out of retirement, he recaptured the 1956 Olympic crown at Melbourne with a jump of 53 feet 7 and 1/2 inches. As Milburn (1979) noted, "... to overemphasize one particular phase in the triple jump would be at the expense of the succeeding phase and probably of the overall performance" (p. 7).

Josef Schmidt, 1960 and 1964 Olympic champion, carried this "balanced ratio philosophy" even further. In one meet during the 1960 season, he hopped 19 feet 8 1/4 inches, stepped 16 feet 5 and 1/4 inches, and jumped 19 feet 8 and 3/4 inches, while establishing a world record of 55 feet 10 and 1/4 inches. This performance not only reinforced the balanced ratio philosophy, but also alerted everyone concerned to the importance of maintaining momentum throughout the entire performance of the triple jump. During that performance, Schmidt's resulting ratio was 35.2% for the hop, 29.4% for the step, and 35.4% for the jump. He used fast approach runs and low trajectories during the hop and step in order to conserve momentum for the third takeoff (Doherty, 1976). This style of jumping has now become known as the "Shallow or Flat Technique" (Bullard & Knuth, 1977).

Before Schmidt had established his world record, however, the Soviet Union gave notice that it was an emerging triple jump power when in 1953, Shcherbakov usurped the world triple jump record from da Silva in 1953 with a leap of 53 feet 2 and 3/4 inches. The reign was short lived, however, as da Silva recaptured the record in 1955 when he jumped 54 feet 4 inches. In 1958, the Soviet triple jumpers finally gained dominance when Ryakhovskiy broke da Silva's record with a jump of 54 feet 5 and 1/4 inches. One year later Fyedoseyev, another Soviet triple jumper, increased that record by jumping 54 feet 9 and 1/2 inches. These jumpers reverted back to a dominant hop technique utilized so effectively by the great Japanese jumpers. This style of triple jumping in which the hop distance was emphasized was named the Russian technique.

In the 1968 Olympic Games in Mexico City, Victor Saneyev captured the title with a world record jump of 57 feet 3/4 inches and established the Soviet Union as the world's perennial triple jump power. Even more amazing than his world record performance was the technique he used to establish it. He startled everyone by using a double arm swing during the takeoff of all three phases. One and one-half strides before the takeoff board he positioned the arm opposite his takeoff leg against his abdomen until the critical moment at the takeoff board when it joined the free swinging arm as it continued its swing forward and upward (see Figure 1.1). This style of double arm hop takeoff is now called "Arm and a Half Method" (Bullard & Knuth, 1977).

Figure 1.1. The arm and a half method.

Saneyev prepared for the second and third takeoffs during the flight of the hop and the step by swinging both arms backward until they were behind his body. As the second and third takeoffs began, he drove them forward and upward together (see Figure 1.2).

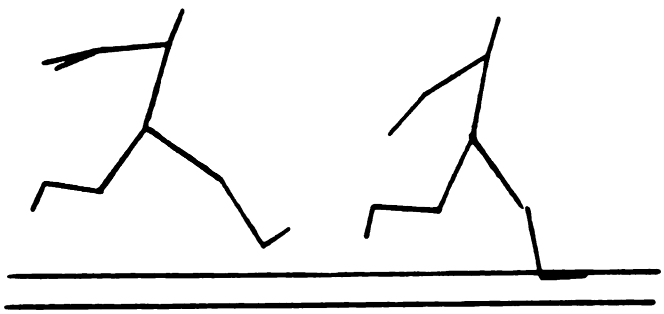

Figure 1.2. Use of double arm swing during the second and third takeoffs.

After Saneyev won the 1968 Olympics, the double arm technique quickly spread across Eastern Europe. Because of the international success of jumpers from the Eastern

European countries, the popularity of this style of triple jumping quickly spread to all parts of the world. Saneyev's performance also sparked a controversy that still persists today as to the advantages and disadvantages of using a double arm swing during all three takeoffs.

After observing Saneyev's historic leap and then requiring his triple jumpers to utilize this new technique, international track and field authority Gabor Simonyi announced, "I personally think a parallel double arm swing can begin at the first takeoff. I have tried it and have had some of my athletes try it. We thought it was not difficult at all, and it certainly made the whole action of triple jump more uniform" (Simonyi, 1970, p. 9). He also asserted:

> Since this is a deliberate and admittedly unnatural action, it must be practiced and learned. The orthodox triple-jumper places no special emphases on the arms.The arms perform whatever body balancing is needed, and its movements are involuntary, almost automatic.
>
> The advantage of a double arm-swing is that it forces the jumping leg to exert greater force at take-off. The vigorous arm action acts on the legs much in the way that a force would on a compressed spring coil. The more the coil is compressed the more it will rebound when released (Simonyi, 1970, p. 9).

Track and field researcher Larry Adams agrees with Simonyi's assessment.

> Although the "double arm pump" is a less natural end movement than the normal cross-coordination of the arms and legs, this technique appears to have several advantages if the athlete intends to improve the magnitude of the application of force and the transfer of momentum, in addition to helping to maintain balance (Adams, 1975, p. 213).

Ernie Bullard and Larry Knuth, track and field coaches and authors of the book Triple Jump Encyclopedia, have also voiced strong opinions on this controversy:

> ... On closer examination of the event, and after much experience with all levels of ability in learning this event, the authors believe the double arm to be teachable and slightly superior to single arm action.
> Ideally, maximum thrust off the board is what all triple jumpers want to utilize. With double arm action, the authors feel, maximum thrust can be handled with a flat hop and better balance (Bullard & Knuth, 1977, p. 125).

They take issue, however, with the employment of the parallel double arm swing:

> Simonyi's suggestion for accomplishing this action off the board greatly hinders horizontal speed, for he suggests the jumper carry both his arms backwards during his last two strides. This action is a slow, awkward, and braking action, whereas Saneyev's and Gentile's technique is efficient and aids transference of momentum (Bullard & Knuth, 1977, p. 126).

The method that these authors advocate is the "Arm and a Half Method" previously described. Malcolm Arnold, British National Coach, also prefers the "Arm and a Half Method:"

> Those triple jumpers who use double arm swing technique from the first take-off (e.g. Saneyev) should note that the double armed alignment happens as the jumper leaves the board. A number of jumpers in Britain are using a high jump type of alignment, where the double arm phase happens before and through take-off. This can lead to a wasteful loss of horizontal speed before the first take-off (Arnold, 1978, p. 17).

Many coaches from the United States, however, have been reluctant to adopt either of the double arm hop techniques. This reluctance probably persists because most American triple jumpers began their careers as long jumpers; and, once the single arm motion utilized in the long jump becomes habit, the transition to the double arm technique does not come easily. Besides this, prominent coaches in the United States and abroad have openly denounced any form of the double arm technique.

Fred Wilt, coaching certification coordinator for the Canadian Track and Field Association, flatly denounced the double arm swing during the hop takeoff:

> It is my opinion, formulated after counting individual frames from 16mm 64-frames-per-second triple, long, and high jump movies, that taking one arm out of normal running phase to align it with the other arm behind the body in preparation for a double-arm takeoff, will inevitably cause the athlete to reduce approach or run-up speed. It may be that there are athletes who can take one arm out of normal running phase in preparation for a double-arm takeoff action without reducing approach speed in the final stride, but I have not yet been able to find one on film, and rather doubt that I shall. For this reason I do not advocate using double-arm action at takeoff for the hop phase of the triple jump (Wilt, 1978, p. 55).

Researchers Young and Marino agreed with Wilt:

> Since the takeoff time for the hop can be as short as 0.12 seconds, a double arm action should not be used in order to avoid a prolonged takeoff. It is not used in the long jump where greater distance and Vv at the takeoff is required and the takeoff time longer, so it should not be necessary for the hop where submaximal vertical forces are required. Whether the double arm action should be used for the step and jump would depend on the

> individual athlete's ability to complete it effectively in a short time (Young & Marino, 1984, p. 14).

It is apparent that a variety of opinions exist among triple jump authorities as to the most effective use of the arms during the three takeoffs.

PURPOSE OF THE STUDY

The purpose of this study was two fold. First, this study compared the performance of novice triple jumpers to published findings of elite male triple jumpers on many of the important variables that determine triple jump performance. Second, this study investigates the effect of the single arm style and the parallel double arm style of takeoff on triple jump performance.

NEED FOR THE STUDY

With the exception of Wilt (1978) who related changes of approach speed to hop arm style, no other quantitative study has been done which analyzes the effects of arm style on triple jump performance. Each of the coaches and researchers previously cited have reasonable arguments on which to base their opinions, but with the exception of Wilt (1978) their arguments were not supported by quantitative research.

In fact, there has been very little quantitative research done on any aspect of the triple jump. Because of this, any coach who attempts to voice an educated opinion on any factor that affects triple jump performance is working under a severe handicap. For the most part, their opinions would have to be derived from two sources, qualitative triple jump research such as the ones already cited (Simonyi, 1970; Adams, 1975; Bullard & Knuth, 1977; Arnold, 1978) and both qualitative and/or quantitative long jump research. Because of the limited quantitative research on triple jump technique, it is questionable whether accurate qualitative statements about the event can be made at this time with assurance of validity. Furthermore, the appropriateness of applying the results of long jump research to triple jump analysis is also dubious. Ramey (1982) explained why:

> The obvious difference is that there are three support and flight phases in the triple jump compared to just one support and flight phase in the long jump. However each support-flight phase pair of the triple jump essentially resembles the support-flight phase pair of the long jump. The resemblance just noted is unfortunate because many novice coaches and jumpers attempt to extrapolate the knowledge and experience from the long jump to the three phases of the triple jump. Such an extrapolation does not work. In doing a biomechanical analysis one can take advantage of the resemblance, but care must be exercised to account for the differences (p. 289).

The neglect that the triple jump has suffered in the research lab is primarily due to three factors: 1) the popularity of the long jump in the United States, 2) the amount of time and effort necessary to collect data on an event that has three takeoffs, and 3) the difficulty of analyzing data for three interrelated support phases. Until the skills that have been acquired by long jump researchers are applied to triple jump research, the progress of American coaches and athletes in this event will continue to lag behind their Eastern European counterparts.

SPECIFIC AIMS OF THE STUDY

Any preparatory movements made prior to touchdown will affect the body's configuration during the support phase. The body position during the support phase in turn will affect takeoff mechanics. This suggests a direct link between preparatory movements such as arm style, the intervening mechanical variables, and the total distance one can triple jump. A possible causal model for the interrelationship between these three factors is illustrated in Figure 1.3.

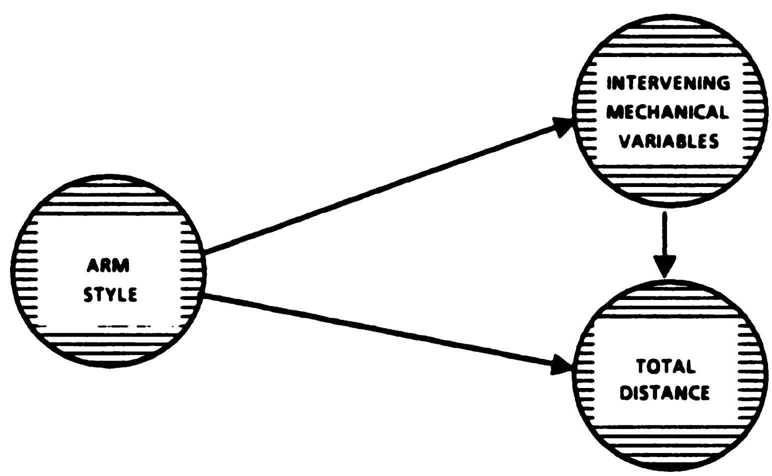

Figure 1.3. Causal model for the interrelation between arm style, the intervening variables, and the total distance jumped.

The specific aim of this study then was to determine the effects of the arm style used during each support phase on the intervening mechanical variables and the total distance jumped.

RESEARCH HYPOTHESES

Three hypotheses were developed to determine the effects of arm style on the intervening variables and the total measured distance jumped. These hypotheses are stated below.

Ho(groups): There is no difference between triple jumpers who use the single arm and the double arm style of take-off on the total distance jumped or any of the intervening variables under consideration.

Ho(phases): There is no difference between the three phases with respect to the intervening variables under consideration when examining triple jumpers regardless of the arm style utilized.

Ho(patterns): There is no difference between the patterns of the single arm group and the double arm group with respect to the way each intervening variable under consideration is apportioned across the three phases.

Choice of Arm Style

Three arm styles commonly used in the triple jump were identified as possible treatment variables for this study: the parallel double arm swing, the arm and a half, and the single arm swing. It should be noted that these names denote the use of the arms during the first takeoff only. They do not distinguish between styles of triple jumping that utilize combinations of these three arm styles for the second and third takeoffs. For this study, one group of jumpers was trained to use the single arm style during each of the three support phases while a second group was trained to use the parallel double arm style during each support phase. Figure

1.4 illustrates the single arm style of triple jumping. Figure 1.5 illustrates the parallel double arm style of triple jumping. During further discussions, the parallel double arm style will be referred to as the double arm style.

Selection of Intervening Variables

It would be inadvisable to conduct an investigation that focused solely on the effects of hop arm style on the distance that one can triple jump. This type of investigation would take on the character of a "black box" study in which one directly manipulates the treatment variable, in this case arm style, and then determines its effect on the outcome variable, the measured distance jumped. If this type of investigation had been conducted, the researcher would have remained totally unaware of the mechanisms that created the observed outcome. In order to jump great distances, the intervening mechanical variables must be optimized. Therefore, it is not only important to understand how the use of the arms during each takeoff affects the distance one can triple jump but also how it affects the intervening mechanical variables.

The intervening mechanical variables that were investigated in this study relate to the issues raised by the coaches and researchers cited in the introduction to this chapter, i.e., the effects of hop arm style on triple jump performance. Therefore, intervening mechanical variables were chosen in order to help ascertain the effects of hop arm style on 1) conservation of horizontal velocity across

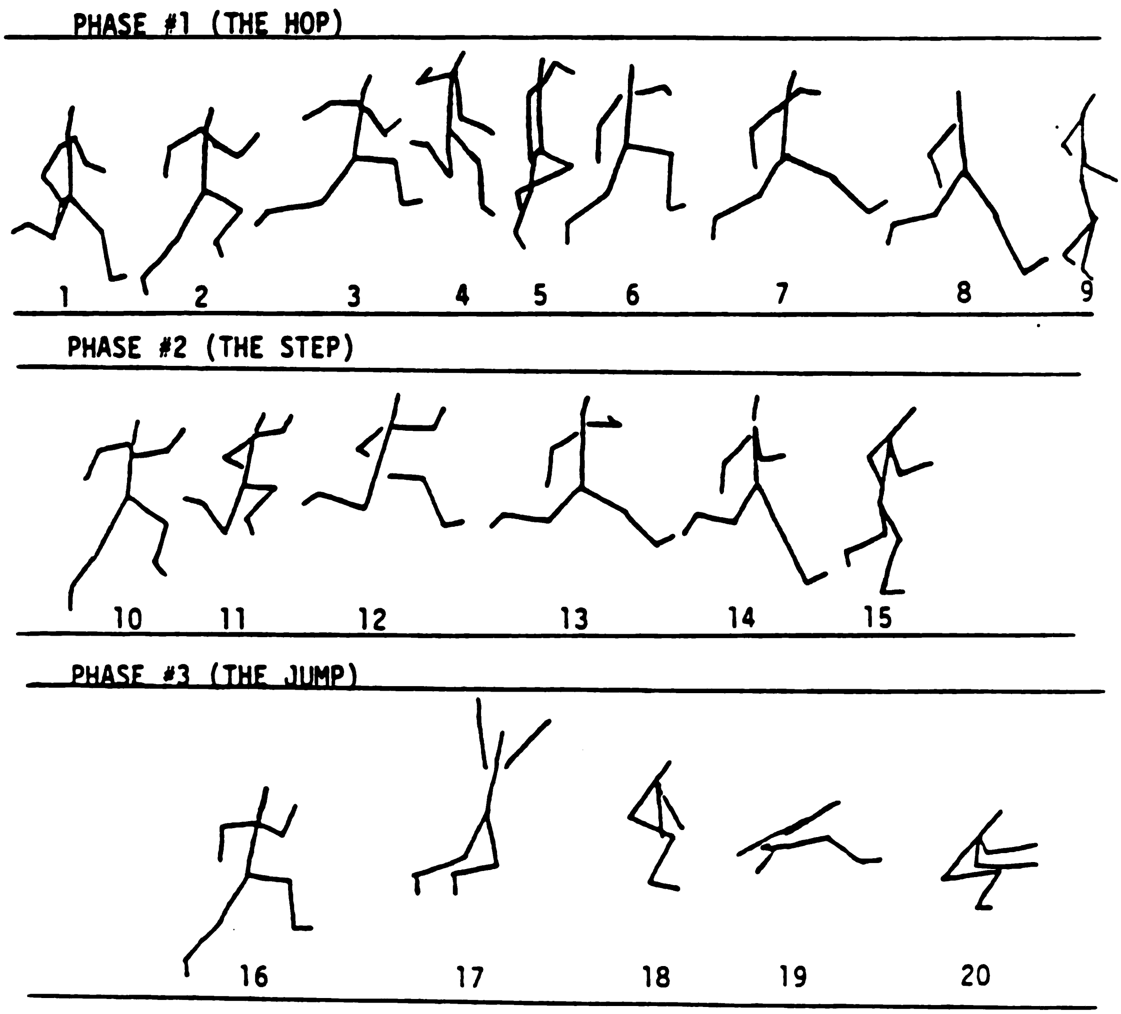

Figure 1.4. Single arm style.

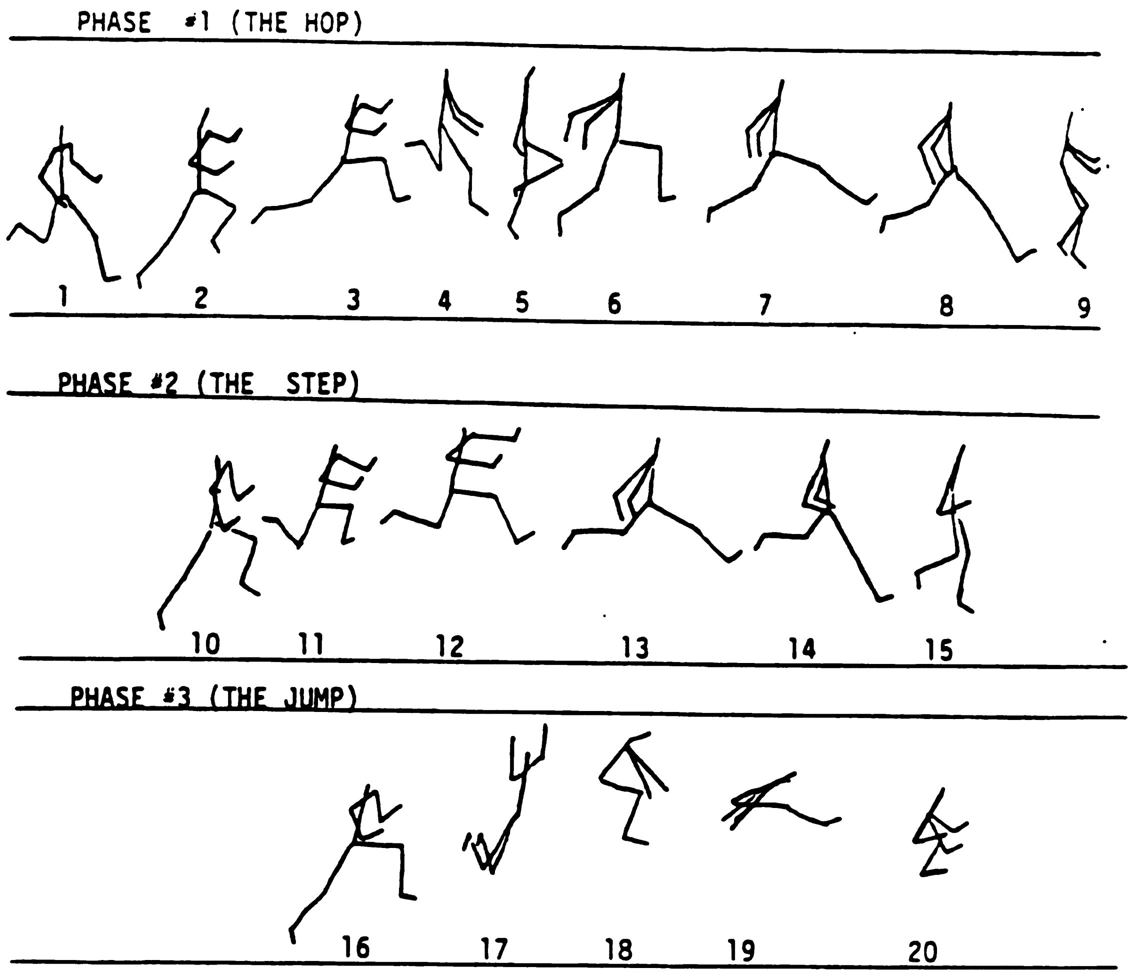

Figure 1.5. Parallel double arm style.

phases, 2) force application during each takeoff (Simonyi, 1970; Adams, 1975; Bullard & Knuth, 1977), and 3) balance (Simonyi, 1970; Adams, 1975; Bullard & Knuth, 1977). Figure 1.6 list these variables. They are defined in Appendix A.

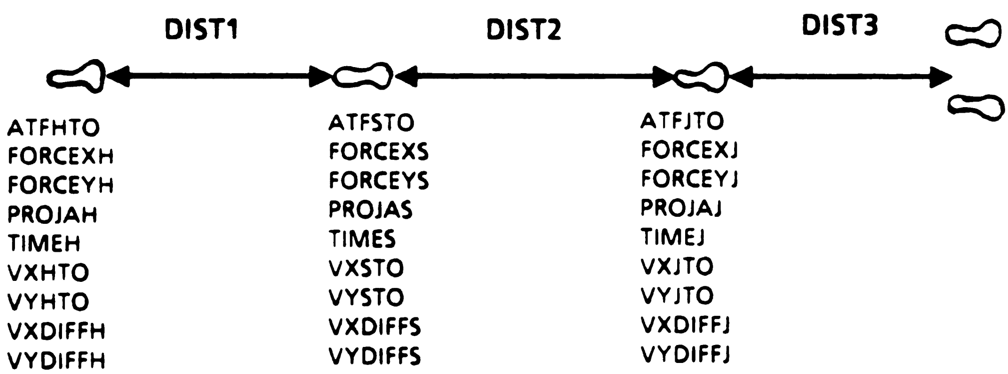

Figure 1.6. The intervening variables under consideration.

Limitations of the Study

Before this study was conducted, it was necessary to determine whether certain limitations to this study could be overcome. These factors relate to limited, sample size, limited time available for training, and the lack of adequate force data collection equipment.

The sample for this study was drawn from a high school female track team. These subjects had had no prior training in the triple jump. Because of the amount of time and motivation necessary for beginners to learn to triple jump, as well as the high risk of injury, it was difficult to find volunteers for this study. Eight subjects originally volunteered for the study; one subject, however, eventually dropped out. A sample as small as this limits the power of the test statistic to detect true difference between the groups. In order to diminish the variability between subjects, the subjects were matched on their long jump ability (see Appendix B). Matching was performed after the subjects were randomly assigned to either the single arm group or the double arm group.

The training period was limited to four weeks; moreover, because of other training demands on the subjects, each triple jump training session was limited to one half hour per day. These time limitations affected the level of proficiency that the subjects could attain. To insure that the jumpers did not use an approach run that was faster than they could control, the distance of the approach run was limited to ten steps. The slower approach run gave the inexperienced jumpers time to execute each takeoff efficiently and without fear of injury, but did not allow them time to reach top speed. Because of the limited approach run distance, no attempt was made to ascertain the effects of hop arm style on approach run velocity.

In order to make direct force measurements on all three support phases during a single performance, three force plates must be mounted in a triple jump runway. At present, there are no research facilities in the United States that have this type of arrangement. There are, however, long jump research facilities with a single force plate mounted in a long jump takeoff board. Using a single force plate and a procedure developed by Ramey (1982), it is possible to obtain force records for each support phase in the triple jump. Ramey`s procedure, however, does not allow one to measure forces generated during all three support phases in a singletrial. Because force plates used in long jump research are positioned close to the landing pit, it is impossible for the jumper to land in the sand pit at the completion of the trials in which the forces for the first and second support phases are measured; instead, they must land on a port-a-pit. This makes it impossible to get an accurate measurement of the complete jump. Because of this limitation, Ramey's procedure was incompatible with this study's research hypotheses. Therefore, the average forces generated during each support phase were calculated by using the impulse-momentum relationship and data obtained through the use of high speed cinematographic techniques. This procedure has been used by Fukashiro et al. (1981) and Hay and Miller (1985).

.CHAPTER 2

REVIEW OF LITERATURE

In spite of the advances that have been made in biomechanical analysis of the long jump over the years, quantitative research on the triple jump has lagged far behind. Triple jump researcher Peter Milburn (1979) lamented this fact when he stated:

> The most notable observation gained from the investigator's review of literature related to the triple jump was the lack of scientifically-orientated research, particularly from non-European sources. The preponderance of the literature reviewed was of the type that could be described as 'popular' literature, restricted to coaching methods and coaches' opinions which were mainly based upon their experience, observation or experimentation (Milburn, 1979, p. 16-17).

Unfortunately, very little quantitative research has been done since Milburn's observation. Most of the research done on the triple jump is qualitative in nature as described in Chapter 1 of this study, (Dyson, 1977; Simonyi, 1970; Adams, 1975; Doherty, 1976; Bullard & Knuth, 1977; Arnold, 1978; Wilt, 1978). In qualitative research, the investigator observes the event via direct visual observation, films, or video records and then attempts to evaluate the results of the performance in terms of some ideal model and sound mechanical principles (Hay & Reid, 1982; Ramey, 1982).

The quantitative research that has been done on the triple jump has mainly followed the example of early long jump researchers such as Cureton (1935) who applied techniques used in solving general ballistics problems to problems in track and field events. Cureton believed, "the specifications for a broad jump of any distance can be computed by using the projection laws" (p. 9).

Researchers who have applied the ballistics approach to long jump and triple jump analyses have focused on three concerns (Hay & Reid, 1982):

1) can the distance of the jump be predicted by knowing the takeoff velocity, relative height of the center of mass at takeoff, and projection angle?

2) which of these three factors is the most influential in determining the length of the jump?

3) will an increase in one of these factors produce a greater improvement in the performance than a comparable increase in some other factor?

Even though most of the quantitative research reported in the triple jump is of the ballistic type, this type of research is only the first step in the analysis of the triple jump as Ramey (1982) has made clear. He stressed the need to incorporate force measuring devices into triple jump research in order to acquire force records of each support phase. These force records can be used to study the changes in velocity during each support phase by using the impulse-momentum equations of mechanics (Ramey 1982). These equations also provide valuable information as to how the takeoff velocities are acquired.

The ballistics approach and the use of the impulse-momentum relationship in triple jump research focus on the mechanics associated with the motion of the jumper's mass center and the forces associated with the support phases. Ramey (1982) has also stressed the need to explore the "reorientation phenomenon" that occurs during the flight of the hop, step, and jump phases of the triple jump. Through the use of the conservation of angular momentum equation, it is possible to study how the athlete positions the limbs in order to prepare for a suitable landing. As of this writing, no studies have been done which analyze the use of angular momentum in triple jumping.

THE USE OF THE BALLISTICS APPROACH TO TRIPLE JUMP RESEARCH

Theoretical Background To The Ballistics Approach

Conclusions derived from the ballistics approach to long jump and triple jump research are based on the same theoretical model used in general ballistics problems. This model is based on a straightforward application of Newton's Laws of motion. From the Law of Inertia, it is known that if some external force did not act on the jumper after takeoff the jumper would continue with uniform motion along a linear path forever. Two forces act on the individual to alter the straight line path of motion: 1) gravity, which close to the surface of the earth constantly accelerates the individual toward the earth at a rate of the local value of the acceleration, which is usually taken as $9.8 m/s^2$ and 2) fluid forces such as drag and cross wind forces. If a projectile were under the influence of the earth's gravitational field and in a vacuum, its trajectory would closely approximate a parabola. If the projectile were acted on by fluid forces, its parabolic trajectory might also be altered.

The magnitude of the fluid forces depends upon the shape and mass of the jumper, the density of the air, the wind currents, and the length of the path along the trajectory. These effects seriously complicate the calculation of the trajectory (Hagen, 1982). To avoid these complications, long jump and triple jump researchers make a number of assumptions: 1) the range of the jump is short in relationship to the size of the earth and that the jumper is projected over a flat surface; 2) the gravitational acceleration at the site of the performance is known and constant; and 3) fluid forces such as drag, cross wind forces, and the Coriolis effect do not affect the trajectory of the jump (Hagen, 1982). In effect, long jump and triple jump researchers assume that the jump is performed in a vacuum. Given these assumptions as well as the combination of the oblique takeoff angle and the constant pull of gravity, the flight path of the center of mass of the long jumper and the triple jumper describes a perfect parabola (Dyson, 1977).

Equations of Motion

The equations of motion used by long jump and triple jump researchers in studying ballistics problems have been derived from two cases.

Case 1: The height of the center of mass at takeoff (y_o) is equal to the height of the center of mass at landing (y_f). Thus $y_o = 0$ and $y_f = 0$.

Case 2: The height of the center of mass at takeoff is higher than the height of the center of mass at landing. Thus, $y_o = h$ and $y_f = 0$.

Case 1:

The model for Case 1 is shown in Figure 2.1.

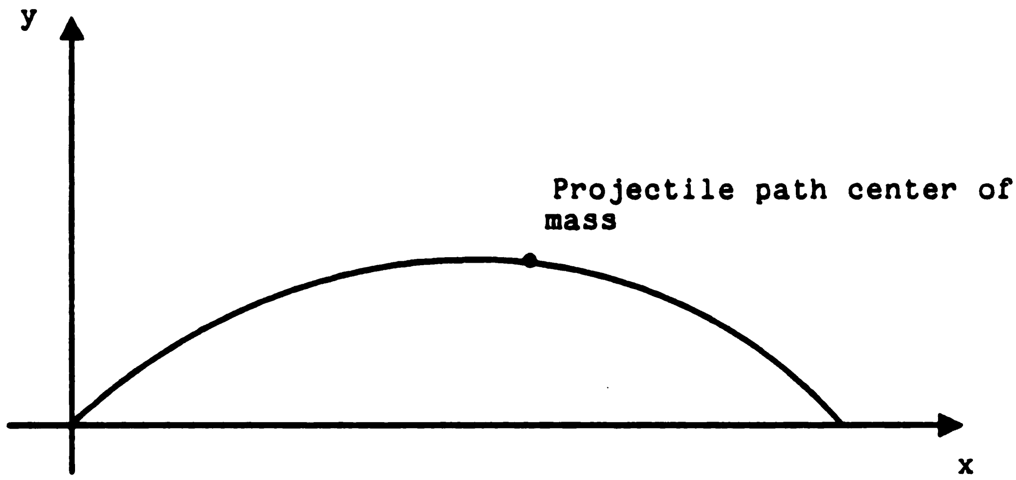

Figure 2.1. Trajectory of projectile mass center when y_o and $y_f = 0$.

The equations of motion for Case 1 are given in Equation 1.

$$m \frac{d^2x}{dt} = 0$$

$$m \frac{d^2y}{dt} = -mg \qquad (1)$$

The initial conditions are given by Equation 2.

$$\frac{dx}{dt} = v_o \cos\Theta_o \quad x_o = 0$$

$$\frac{dy}{dt} = v_o \sin\Theta_o \quad y_o = 0 \qquad (2)$$

Integrating the equations of motion and inserting the initial conditions, one obtains the horizontal and vertical position equations found in Equations 3.

$$x = v_o \cos\Theta_o + x_o$$

$$y = v_o t \sin\Theta_o - 1/2gt^2 + y_o \qquad (3)$$

This assumes that we are starting from the origin.

To find the time when the jumper's center of mass returns to the takeoff height, set y = 0.

$$t = \frac{2V_o}{g} \sin\Theta_o \qquad (4)$$

Equations 3 gave us x and y as a function of the common parameter t, the time of flight. By combining and eliminating t from them, we obtain Equation 5.

$$y = (\tan\Theta_o)x - \left(\frac{g}{2V^2{}_o \cos^2\Theta_o}\right)x^2, \qquad (5)$$

which relates y to x and is the equation of the trajectory of the projectile. Since V_o ,Θ_o, and g are constants, this equation has the form $y = a + bx + cx^2$, the equation of (6) a parabola.

We can find the range R by setting y = 0, which corresponds to ground level in Equation 5 and solving for x.

$$R = \frac{V^2_o \sin 2\Theta}{g} \qquad (7)$$

Thus with g constant, the horizontal range for Case 1 is dependent on V_o and Θ_o, the magnitude and direction of the initial velocity, respectively.

Case 2:

It became apparent to contemporary long jump and triple jump researchers that Case 1 was the incorrect model and that for events that exhibit ballistic motion the height of takeoff is always higher than the height of landing. Therefore, Case 2, in which $y_o = h$, provides a better model. This model is shown in Figure 2.2.

The equations for motion in Case 2 are the same as before, i.e., Equations 1, but on integrating Equations 1 the following results are obtained:

$$x = v_o t \cos\Theta_o + A$$

$$(8)$$

$$y = v_o t \sin\Theta_o - 1/2gt^2 + B$$

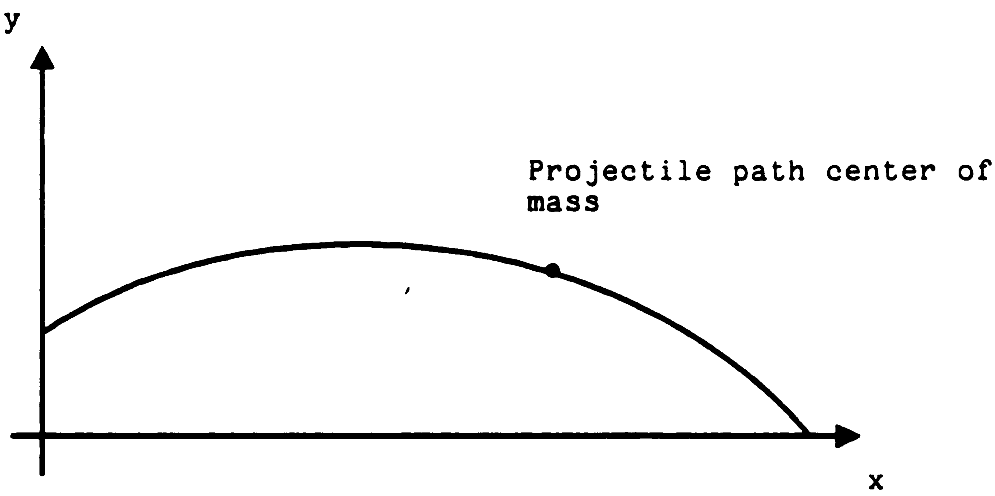

Figure 2.2: Trajectory of projectile mass center when $y_o = h$ and $y_f = 0$.

where A and B are constants. Since, at t = 0, x = 0, y = h, we have A = 0 and B = h, giving

$$x = v_o t \cos\Theta_o$$
$$y = v_o t \sin\Theta_o - 1/2gt^2 + h \qquad (9)$$

We still, of course, have parabolic motion, but the formula for the flight time, t, changes to reflect the additional vertical distance the projectile must fall. It now becomes

$$t = \frac{v_o \sin\Theta_o + [v_o^2 \sin^2\Theta_o + 2hg]^{\frac{1}{2}}}{g} \qquad (10)$$

The formula for the range, R (value of x when y = 0) will also change.

$$R = \frac{v_o^2 \sin\Theta_o \cos\Theta_o + v_o\cos\Theta_o\left[(v_o \sin\Theta_o)^2 + 2hg\right]^{\frac{1}{2}}}{g} \quad (11)$$

Equation 11 shows that for Case 2, the range of a projectile is dependent upon three factors: 1) speed (V_o), 2) angle (Θ_o), and 3) height of takeoff (h).

Range Models in Long Jump and Triple Jump Research

In applying general ballistics problems to long jump research Cureton (1935) used the model for Case 1. He not only assumed that $y_o = y_f$, but also that the jumper had no anatomical properties and was but a point in space. Because projectile problems in athletics involve the use of the human body, the problem of how to improve the range is much more complicated than in point mass ballistics problems. Therefore, it is necessary to develop a definition for range in athletic situations. Hay and Reid (1982) have suggested that performances involving projectile motion can best be studied when the range can be divided into a series of lesser distances. "In these cases," they state, "the division of the result is made so that the part of the result associated with the airborne motion of the body is separated from the part (or parts) associated with the nonairborne motion. The further development of the model then proceeds with relative ease because factors that determine the result of the airborne motion--usually the most important part of the total motion--are well known. They are, of course, the speed, angle, relative height of release and the air resistance encountered in flight" (p. 271). Using this argument, Hay and Reid have developed a model which shows the division of the range of the long jump. This model is shown in Figure 2.3.

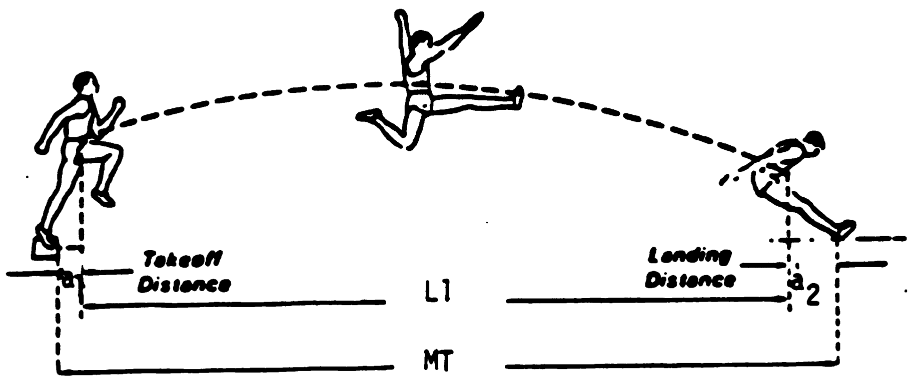

Figure 2.3 Range model for the long jump.
James G. Hay, J. Gavin Reid, THE ANATOMICAL AND MECHANICAL BASES OF HUMAN MOTION, 1982, P. 268. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

where: ML = The total measured distance for the long jump

a_1 = The takeoff distance: the horizontal distance from the foul line to the jumper's center of mass at takeoff

a_2 = The landing distance: the horizontal distance from the jumper's center of mass at touchdown to the mark made in the sand that is closest to the foul line

L_1 = The flight distance: the horizontal distance traveled by the jumper's center of mass while airborne

The total measured distance in the long jump is the sum of its takeoff, flight, and landing distances.

$$ML = a_1 + a_2 + L_1 \qquad (12)$$

Ramey (1982) has developed a similar model for the triple jump. His model is shown in Figure 2.4.

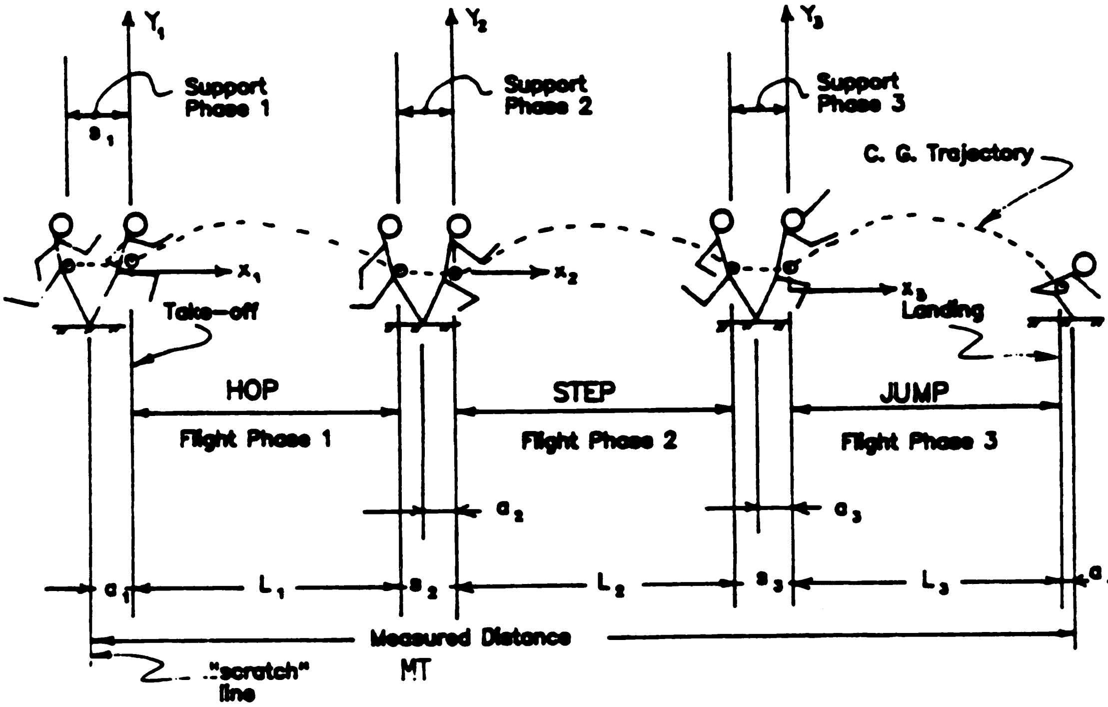

Figure 2.4 Range model for the triple jump.

where: MT = the total measured distance of the triple jump

a_1 = The hop takeoff distance: the horizontal distance from foul line to the jumper's center of mass at takeoff

a_2 = The step takeoff distance: the horizontal distance from the point where the toe leaves the ground to the jumper's center of mass at takeoff

a_3 = The jump takeoff distance: the horizontal distance from the point where the toe leaves the ground to the jumper's center of mass at takeoff

a_4 = The landing distance: the horizontal distance from the jumper's center of mass to the mark made in the sand that is closest to the foul line

s_1 = The distance traveled by the center of mass during support phase 1

s_2 = The distance traveled by the center of mass during support phase 2

s_3 = The distance traveled by the center of mass during support phase 3

$L_i (i=1,2,3)$ = distance traveled by the center of mass during flight phase i

The total measured distance in Ramey's triple jump model is a summation of the takeoff distance, the landing distance, the distance traveled by the center of mass during support phases two and three, and the distance traveled during flight phases one, two, and three:

$$MT = a_1 + a_4 + s_2 + s_3 + \sum_{i=1}^{3} L_i \qquad (13)$$

Over the years, there has been much discussion and debate as to what is the optimal contribution of each phase distance to the total distance. Nett (1961) suggested that the optimal percent contribution of each phase should be 35%, 30%, and 35% for the hop, step, and jump respectively. He stated that when the hop contribution was greater than 38%, the horizontal takeoff velocity decreased considerably. He also stated that when the hop contribution was between 20% and

30%, there was no decrease in the horizontal velocity, but the athlete could not jump as far. Below is a list of researchers and the means of the percent phase contributions they found for elite male triple jumpers.

Researcher	**HOP**	**STEP**	**JUMP**
Milburn (1979)	36.3%	31.3%	32.4%
Smith and Haven (1982)	33.6%	28.9%	37.5%
Fukashiro (1981)	36.9%	29.1%	34.0%
Hay and Miller (1985)	35.4%	29.4%	35.3%

As can be seen from the findings listed above, the optimal contribution of the the phase distances varied with each study. Hay's and Miller's (1985) findings came closest to the contributions suggested by Nett (1961).

Most modern coaches and researchers believe that the optimal contribution of the phase distances is embodied in two styles of triple jumping, the Polish Style and the Russian Style. The Polish Style triple jumpers use great approach speed and keep their trajectory low during the hop and step flights. This seems to allow them to maintain momentum throughout the performance so that they can place their emphasis on the jump phase (Doherty, 1976). McNab (1968) characterized the Polish Style as having phase contribution of approximately 35%, 29%, 36% for the hop, step, and jump distances, respectively. The Russian Style triple jumpers acquire their longest phase distance during the hop phase. They also attempt to achieve a long step distance. Due to diminished momentum, however, the jump phase is usually shorter than the hop phase in the Russian Style (Doherty, 1976). McNab characterized the Russian Style as having phase contribution of approximately 39%, 30%, and 31% for the hop, step, and jump phases, respectively.

In their study of the twelve finalists in the triple jump at the 1984 Olympic Games, Hay and Miller (1985) categorized the performances of the finalists into the Russian and Polish styles. Seven of the finalists used the Russian Style. They found that "none of the seven, however, recorded ratios in which the hop phase was as overwhelmingly dominant as suggested by McNab for the Russian technique" (p. 189). However, Hay and Miller (1985), also found that the remaining five triple jumpers who used the Polish Style had phase contributions that were close to those suggested by McNab (1968). Hay's and Miller's (1985) findings were as follows:

	HOP	STEP	JUMP
Russian Style	36.4%	29.5%	34.2%
Polish Style	34.4%	29.3%	36.3%

In spite of the extensive research that has been devoted to studying phase contributions, many prominent coaches and researchers believe that it is a mistake to encourage triple jumpers to attempt to attain determined phase contributions (Ganslen, 1964; Dyson, 1977; and Bullard & Knuth, 1977). Dyson (1977) argued:

> The basic principle in the triple-jump is that no one phase must be stressed to the detriment of the overall effort. But there can be no precise ratio of distance between the hop, step and jump because of the

> differences in athletes (in speed, spring, strength, weight, flexibility, proportions, etc., etc.). Certainly, no triple-jumper apportions his effort in exactly the same way from one jump to the next (pp. 194-195)!

The Use of Range Formulas in Prediction Models

The range formula for Case 2 (Equation 11) illustrates the relationship that exists between the takeoff velocities, angle of projection, and the relative height of the center of mass. One use of this formula by long jump and triple jump researchers has been to predict how far a long jumper or triple jumper can jump.

Dyson (1977) used Equation 11 to predict the maximum range for the long jump. He predicted that a long jumper who could takeoff with a horizontal velocity of 36 feet per second and raise the center of mass 3 feet at that instant could long jump 37.5 feet. In order to make this prediction Dyson made two assumptions:

1) that the jumper's center of mass would be 1/2 feet lower at the instant of landing than at takeoff (so that it moves 34.67 feet horizontally in flight), and

2) that the jumper jumps 3 feet further because the center of mass is positioned in front of the board at takeoff and is positioned behind the heels on landing.

Fukashiro and Miyashita (1983) adapted this range formula in order to predict the magnitude of the horizontal and vertical takeoff velocities needed to triple jump 18m. They first made three assumptions:

1) The takeoff distances, H1, S1, and J1 and landing distances, H3, S3, and J3 were constant. Furthermore, the vertical displacement of center of mass between each takeoff and subsequent touchdown were also constant.

2) The percentage of contribution for the three distances are fixed--hop 36.9%, the step 29.1%, and the jump covered 34.0% These percentages were determined by taking the mean phase distances from the trials of fifteen subjects.

3) Air resistance was neglected; therefore, the fight distances, H2, S2, and J2 were determined by knowing three factors: the horizontal takeoff velocity, the vertical takeoff velocity, and the vertical displacement of the center of mass between each takeoff and subsequent touchdown.

Using assumptions one and three, Fukashiro and Miyashita derived a formula to calculate the horizontal displacement of the center of mass for each flight phase. Equation 14 below was used to determine the horizontal displacement of the hop flight phase.

$$H2 = V_x \left[\left(V_y + \sqrt{V_y + 2g(L_1 - L_2)}\right)/g\right] \qquad (14)$$

where, g = acceleration due to gravity (9.8m/s^2)

V_x = horizontal velocity of cm at the takeoff of phase i

V_y = vertical velocity of cm at the takeoff of phase i

$L_1 - L_2$ = the vertical displacement of cm during flight in phase i

Equation 14, which is a modified version of Equation 11, was also used to determine the horizontal displacement for the step and jump flight phases.

Then, through the use of the three assumptions mentioned above and Equation 14, Fukashiro and Miyashita derived three formulas for predicting the distance of the hop, step, and jump phases. These formulas are shown below.

$$0.369 \times D = H1 + H2 + H3$$

$$0.29.1 \times D = S1 + S2 + S3$$

$$0.34 \times D = J1 + J2 + J3$$

where, D is the total distance of the triple jump.

From the above assumptions and formulas, they found that in order to jump 18m, a triple jumper must achieve the following velocities:

	APPROACH	HOP	STEP	JUMP
x	10.7m/s	9.9m/s	8.6m/s	7.3m/s
y	-0.3m/s	2.6m/s	2.1m/s	2.8m/s

Most of the quantitative research in these two events has been concerned with determining which of the three factors is most influential in improving the range and determining the effects of increasing the magnitude of one factor while holding the other two factors constant.

The Importance Of Takeoff Velocity to the Range In the Triple Jump

In general, the horizontal distance an object travels is determined by multiplying the object's average horizontal velocity by the time involved (see Equations 3). This relationship between horizontal distance, horizontal velocity, and time also applies to jumping. The range or horizontal distance that a jumper can attain is directly related to both the horizontal velocity of the jumper's center of mass at takeoff and the flight time. Thus, the performance of a long jumper or triple jumper can only be improved by increasing the horizontal velocity at takeoff(s) or by increasing the time(s) of flight(s) (Hay & Reid, 1982).

As a projectile ascends, the effect of gravity causes the velocity of the projectile to be reduced 9.8m/s every second until it reaches a vertical velocity of zero at the peak of its flight. The pull of gravity then causes the projectile to descend with a constantly increasing velocity of the same magnitude. When the object reaches the height at which it was released, it will have regained its initial vertical velocity (Hay & Reid, 1982). Because the magnitude of an object's vertical velocity during the ascent is equal to its vertical velocity during descent, the time of ascent and descent will also be equal. This relationship between vertical velocity at takeoff, gravity, and the flight time is shown mathematically in Equation 4.

$$t = \frac{2v_0 \sin\Theta_0}{g} \qquad (4)$$

Therefore, because gravity is a constant, the vertical velocity at takeoff determines the flight time (Hay & Reid, 1982).

A model of the mechanical factors that determine the range of a projectile is shown in Figure 2.5.

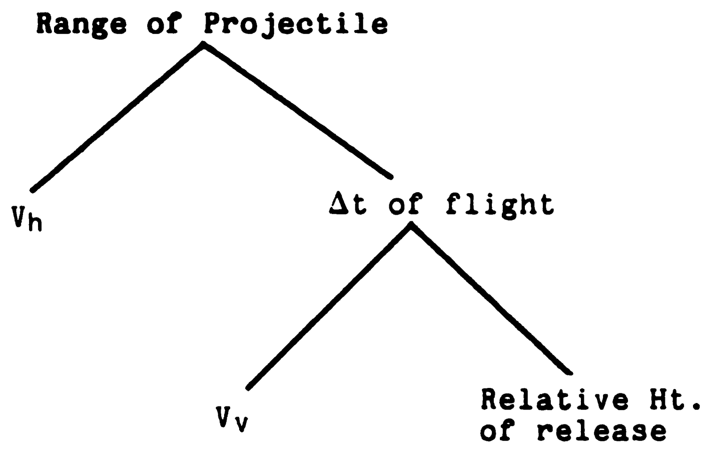

Figure 2.5. Model of the mechanical factors that determine the range of a projectile.

Takeoff Velocities in the Triple Jump

Because of the importance attributed to the takeoff velocities in determining the length of any jumping event, the values for the horizontal and vertical velocities are often reported in triple jump studies. Triple jump researchers have analyzed the takeoff velocities for all three phases of the jump. Bober (1974), Milburn (1979) Fukashiro et al. (1981) and Hay and Miller (1985) found the following mean horizontal takeoff velocity values for elite male triple jumpers:

Researcher	HOP	STEP	JUMP
Bober	8.2m/s	7.2m/s	7.0m/s
Milburn	8.99m/s	8.03m/s	7.66m/s
Fukashiro et al.	8.48m/s	7.76m/s	6.59m/s
Hay and Miller	9.42m/s	8.06m/s	6.96m/s

Fukashiro et al. noted that from hop to step there was an 8.5% decrease in horizontal velocity and 15.1% decrease from step to jump. This stepwise decrease in horizontal velocity was the general pattern found by the other researchers cited. Fukashiro et al. also found statistically significant correlations of r = .53 and r = .73 between the horizontal velocity at takeoff and each distance in the hop and the jump respectively. However, they also found an insignificant negative correlation of r = -.37 between the horizontal takeoff velocity and the step distance. In contrast, they found a positive correlation of r = .801 for the vertical takeoff velocity and the step distance. They concluded that, "it is advantageous for the long distance in the step to get relatively high vertical velocity at takeoff" (p. 235).

Bober (1974), Milburn (1979) Fukashiro et al. (1981), and Hay and Miller (1985) report the following mean vertical velocities for each takeoff:

Researcher	HOP	STEP	JUMP
Bober	2.65m/s	2.06m/s	2.59m/s
Milburn	1.79m/s	1.02m/s	2.10m/s
Fukashiro et al.	2.20m/s	1.76m/s	2.10m/s
Hay and Miller	2.09m/s	1.82m/s	2.37m/s

Fukashiro concluded that "the vertical velocity at takeoff in the hop was very similar to the value in the jump, and was significantly smaller in the step than in the hop and the jump" (p. 235). Unlike their findings of an insignificant negative correlation between horizontal velocity and step distance, they found a high positive correlation of 0.801 between the vertical velocity at takeoff and the step distance. The vertical velocity values that Hay and Miller (1985) reported are similar to those reported by Bober (1974) and Fukashiro et al. (1981). Hay's and Miller's values, however, exemplified a higher vertical velocity for the jump in relation to the hop and step than were reported by the other two investigators.

In spite of the importance of the takeoff velocities in determining the range for general ballistics problems, Fukashiro et al. (1981) determined "there was no significant correlation between the total distance and the initial velocities at takeoff except between the total distance and the horizontal velocity in the hop" (p. 235). The correlation between the total distance and the horizontal velocity in the hop was r= 0.570.

Changes in Velocities During Each Takeoff

In general ballistic situations, such as in gunnery or rocketry, both the horizontal and vertical velocities are generated as a result of sudden impetus gained from the firing hammer or the explosion of rocket fuel. Acquisition of the horizontal and vertical velocities in jumping events that involve an approach run, however, is somewhat different. The horizontal velocity is generated during the approach run while virtually all of the vertical velocity is generated during the support phase. Furthermore, some of the horizontal velocity acquired during the approach on the runway is lost during each support phase (Ramey, 1970, 1985). The stepwise decrease in horizontal velocity from hop to step to jump observed by Fukashiro et al. (1981) is a reflection of this loss.

Knowledge of the magnitude of the velocities at the beginning and end of the support phase can yield important information about takeoff mechanisms, but even more information can be gained if one measures the changes in velocities throughout a takeoff. Through the use of high speed cinematography, triple jump researchers have computed the velocities of the center of mass at specific instances in time during each support phase. This allows them to record the pattern of the takeoff velocities at chosen instances in time. Fukashiro et al. (1981) recorded the pattern of velocity change during each takeoff for a 15.33m jump. They reported that "the horizontal velocity decreased during the first half of each takeoff and increased during the second half" (p. 235). They also found that "the vertical velocity increased at an almost constant rate during each takeoff" (p. 235).

The Use of Approach Run Speed as the Cause of the Takeoff Velocities

In order to acquire a full understanding of how takeoff velocities affect the distance jumped, it is important to determine the magnitude and direction of the forces that cause the final takeoff velocities. Fukashiro et al. (1981), Fukashiro and Miyashita (1983) and Hay and Miller (1985) were able to estimate the forces generated by each takeoff through the use of high speed cinematographic techniques and mathematical calculations. Their findings will be discussed later in this chapter. Direct measurements of the forces that cause the velocities to change during each takeoff can only be performed with the use of a force measuring device such as a force plate. When these instruments are not available, long jump and triple jump researchers tend to focus only on the velocity of the approach run as the cause of the takeoff velocities (Campbell, 1971; Dyson, 1977; Ramey, 1978; Milburn, 1979).

Ramey (1978) emphasized the importance of approach speed in the long jump when he stated, "As is well known, the primary variables that determine the success of the long jump are the magnitude (sic) of the horizontal and vertical velocities that the jumper develops on the approach and the take-off area" (p. 24). Horizontal approach velocity for elite male long jumpers has been reported in the range of 9.83m/s to 11.87m/s (Carter, 1969; Karayannis, 1978). As a result of his study, Karayannis concluded that, "long jumpers with greater final velocity did not jump farther, as would be expected, than others with less final velocity" (p. 22). He believed that there were two possible answers to this apparent contradiction: First, those long jumpers who maintained high approach speed to the takeoff board may have failed to place their bodies in optimal takeoff position during the final steps of the approach. Inefficient preparation during this crucial stage of the approach can cause inadequate force application during the takeoff phase. Second, "Assuming that they were prepared for the take-off but they still had a high final velocity, their failure then to jump father may have been due to lack of enough training in loading and yielding force coordination, under high final velocity circumstances. In other words, their action-reaction function is not expected in respect to their velocity" (p. 23).

Dyson (1977) indicated that high approach speed was also important to the the success of the triple jump. "The distance gained in a triple-jump is largely dependent upon the horizontal speed which can be developed in the approach and the extent to which this can be controlled, conserved and evenly apportioned over all three phases--hop, step, jump" (p. 192).

Researchers Susanka et al. (1984) and Hay and Miller (1985) have reported approach speeds in the triple jump for elite triple jumpers that fall at the lower end of the range of the approach speed of elite long jumpers. In comparing the triple jumps of Marinec and Conley during the First World

Championships in Athletics (Helsinki, 1983), Polish researcher Susanka et al. (1984) reported horizontal velocities of 10.8m/s for Marinec and 10.9m/s for Conley. Hay and Miller (1985) reported calculating mean horizontal approach velocities of 10.02m/s and mean vertical velocities of -0.74m/s for the 12 finalists in the 1984 Olympic Games in Los Angeles.

Ganslen (1964) emphasized the differences between the long jump and triple jump approaches. "The approach run and the character of the takeoff are distinctly different in triple jumping when one compares these with the broad jump. The triple jump run has a character much like one associates with pole vaulting. The run in the triple jump must be at the maximum controllable speed, not just the maximum speed" (p. 96).

The Importance Of The Relative Height Of The Center Of Mass At Takeoff

Besides being affected by the vertical velocity at takeoff, the flight time is also affected by the height of the center of mass at takeoff relative to the height of the center of mass at touchdown. Because of its importance in determining the flight time, triple jump researchers have measured the relative height of the center of mass at each takeoff. Their studies demonstrated that definite patterns exist for the vertical displacement of the center of mass across the three support phases.

In comparing the mean values for the height of the center of mass at the instants of touchdown and takeoff during each support phase, Hay and Miller (1985) found a low to higher pattern for these heights during each of the three support phases. Milburn (1979) found the same low to higher pattern for the height of the iliac crest during each of the three support phases.

Hay and Miller (1985) found a definite pattern for the height of the center of mass at the instant of touchdown across the three phases. They reported a high-medium-low pattern for the height of the center of mass. Milburn (1979), who measured the height of the iliac crest at each touchdown, found a medium-high-low pattern across the three support phases.

When measuring the height of the center of mass at the instant of each takeoff, the research teams of Smith and Haven (1982) and Hay and Miller (1985) both found a high-low-medium height pattern across the three takeoffs. Milburn (1979) found the same pattern for the height of the iliac crest. The findings for these researchers are listed below.

Height of Touchdown

Researcher	**HOP**	**STEP**	**JUMP**
Milburn (1979)	.96m	1.01m	.93m
Hay and Miller (1985)	1.03m	.82m	.28m

Height of Takeoff

Researcher	HOP	STEP	JUMP
Milburn (1979)	1.11m	1.04m	1.06m
Smith and Haven (1982)	1.24m	1.06m	1.09m
Hay and Miller (1985)	1.20m	.95m	1.03m

The Importance Of The Angle Of Projection And Touchdown To The Range Of The Triple Jump

The third factor that determines the range of a projectile is the angle of projection. This factor is actually a function of the first two factors, the horizontal and vertical velocities at each takeoff and relative height of takeoff. The vectoral addition of the horizontal and vertical velocity vectors at the instant of takeoff will yield the magnitude and direction of the resultant velocity vector at that instant. When the magnitude of the vertical velocity is much greater than that of the horizontal velocity, the angle of projection will be large. A large vertical velocity and thus a large projection angle is characteristic of activities such as the high jump in which height is the objective. Activities such as the shot put, long jump, and triple jump in which horizontal distance is the objective, generally involve a higher horizontal takeoff velocity than vertical takeoff velocity and, therefore, a smaller projection angle (Hay & Reid, 1982).

In addition, the projection angle is also related to the relative height of takeoff. When the projectile lands at the same level as that from which it was released, as was demonstrated in Case I of projectile motion, the optimum angle is 45 degrees. This was the case that Cureton (1935) used when he pioneered the use of ballistic equations in long jump research. He determined that, "the greatest distance is obtained when the takeoff angle is 45 degrees, with the projection velocity constant at all angles" (p. 9).

In athletic events such as the long jump and the triple jump, however, the level at which the projectile lands is below the level at which it takes off; therefore, these events fit Case 2. It has now been determined by mathematical proofs as well as empirical research that for projectiles that land below the takeoff level the optimum angle of takeoff is always less than 45 degrees. "The exact magnitude of the optimum angle in such cases depends on the velocity and relative height of release" (Hay & Reid, 1982 pp. 134, 136).

Unlike the long jump, however, the angle of projection in each takeoff of the triple jump is also affected by the jumper's need to conserve horizontal momentum throughout each successive phase. This need for conservation causes the angle of projection of the first takeoff in the triple jump to be smaller than that found in the long jump. Dyson (1977) explains why:

> As he cannot change his weight, govern air resistance to any significant extent, nor produce a good jump without maximum (controlled) approach speed, he influences his overall jumping distance by controlling his angles of takeoff and landing, by skillfully (sic) reducing the landing shock, and to a limited degree by driving horizontally on each takeoff.
>
> For the conservation of horizontal speed, ideally, the jumper needs a low-angled takeoff and a steeply-angled landing, but these are incompatible:

> takeoff and landing angles must always be approximately equal, particularly in the hop and step. Therefore, in the hop, for example, where a good jumper gains his distance mainly on approach speed, a comparatively low takeoff angle favours conservation, while the acute angle at which he lands tends severely to check his forward movement (pp. 192-193).

Results reported by Bober (1974), Milburn (1979), Fukashiro et al. (1981), Smith and Haven (1982), Susanka et al. (1984), and Hay and Miller (1985) substantiated Dyson's views on the importance of a low takeoff angle for the hop. The range of hop projection angles reported by the above researchers ranged from 11 degrees to 20 degrees for skilled jumpers. This range is considerably lower than the 18 to 31 degree range reported by long jump researchers Cooper et al. (1973), Flynn (1973), Ramey (1978), Luhtanen and Komi (1979), Stewart (1981), and Hay and Miller (1985). The projection angles for three triple jump studies are listed below. It should be noted that the projection angle values listed below for Milburn (1979) and Fukashiro et al. (1981) were calculated from their velocity data.

Projection Angles in Degrees

Researcher	HOP	STEP	JUMP
Milburn (1979)	11.26	7.24	15.33
Fukashiro et al. (1981)	14.54	12.80	17.68
Smith and Haven (1982)	14.92	12.37	22.38
Hay and Miller (1985)	12.55	12.80	18.83

In each of the three triple jump studies cited above, the projection angle for the jump takeoff was much greater than the projection angle of the hop and step takeoffs. In fact, the range of projection angles for the jump reported in these studies (15-22 degrees) approached reported long jump projection angles. Force vectors diagrammed by Fukashiro et al. (1981) also support these results. These vector diagrams show greater backward lean during the jump support phase than in the previous two takeoffs. These results are most likely a result of the jumper's need to compensate for the diminishing horizontal velocity by maximizing the vertical forces.

THE USE OF THE IMPULSE-MOMENTUM RELATIONSHIP IN TRIPLE JUMP RESEARCH

The ballistics approach provides important information about the relationship between the total distance jumped and the takeoff variables: velocities, relative height of the center of mass at takeoff, and angle of projection. We have also seen that with the aid of high speed cinematography, information about the changes in takeoff velocity during the entire support phase can be acquired. The use of the ballistics approach in conjunction with high speed cinematography, however, is only the first step in the analysis of jumping events. As Ramey (1982) pointed out,

> ..because of the significance of the takeoff velocities,it becomes important to study how the velocities are acquired. This study requires that one consider the forces associated with support phase, since virtually all the vertical velocity is developed during this phase and a portion of the horizontal velocity acquired during the approach on the runway is lost. A force platform is usually used

to record the support phase force histories (p. 254).

By developing a model that illustrates the mechanical factors that determine the takeoff velocities, it is possible to ascertain exactly how the takeoff velocities are acquired. This model is presented below. It was extracted from a more complete model developed by Hay and Miller (1985).

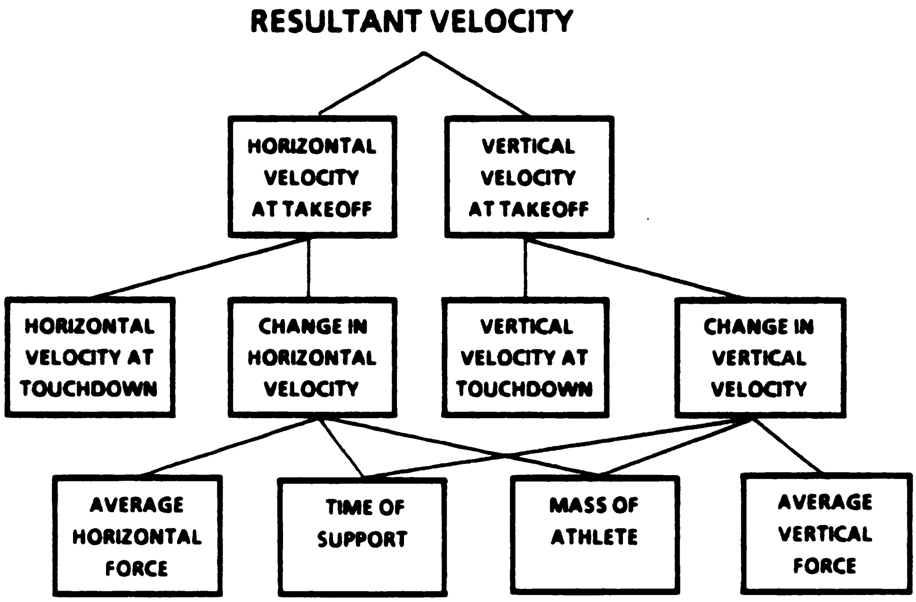

Figure 2.6: Model of the mechanical factors that determine the resultant takeoff velocity.

The model above shows that the takeoff velocities are a result of continuous changes in a number of mechanical factors. For example, the horizontal velocity at the instant the foot strikes the takeoff board is a result of the horizontal velocity generated during the approach run. The change in horizontal velocity during the support phase is mainly a result of three factors: 1) the horizontal forces transmitted to the ground during the support phase, 2) the time for which the foot is in contact with the ground, and 3) the mass of the jumper (Hay & Reid, 1982). The vertical takeoff velocity is a result of a similar series of events.

Hay's and Miller's (1985) model is a result of the simple addition of the velocity at the beginning of the support phase and the change in velocity that occurs throughout that phase. These changes are in direct proportion to the mean force exerted during the takeoff. Determination of the magnitude and direction of the forces generated during each takeoff is an important step in understanding how the jumper conserves the approach momentum and how vertical velocity is generated during each takeoff.

With the introduction of the force plate into athletic research, jump researchers acquired a tool that enabled them to measure directly the forces experienced by the jumper throughout the entire support phase. By applying the impulse-momentum relationship in the form of Equation 15 to force plate data, changes in velocity throughout the entire support phase can be directly related to changes in takeoff impulse experienced by the jumper.

$$F\Delta t = m\Delta v \qquad (15)$$

Ramey (1982) has shown mathematically that the horizontal and vertical takeoff velocities for each support phase of the triple jump can be obtained from the solution of the impulse-momentum equation (15). This solution yields the following relations.

$$(v_x)_i = \frac{\int_{t_a}^{t_b} (F_x)\, dt}{m} + (v_{ox})_i$$

(16)

$$(v_y)_i = \frac{\int_{t_a}^{t_b} (F_y)\, dt}{m} + (v_{oy})_i$$

where, $(v_{ox})_i$ and $(v_{oy})_i$ are the horizontal and vertical components of the mass center velocity at the beginning of Support Phase i and $(F_x)_i$ and $(F_y)_i$ are the horizontal and vertical components of the force vector acting during the support phase. The integration indicated in Equation 2 is to be taken from the time of the beginning of the particular support phase to its end.

By substituting Equation 16 into the range formula for Case 2,

$$R = \frac{v_o^2 \sin\Theta_o \cos\Theta_o + v_o\cos\Theta_o \ [(v_o \sin\Theta_o)^2 + 2hg]^{\frac{1}{2}}}{g}$$

an equation that relates the force, contact time, and initial velocities for a particular flight phase is derived, Equation 17.

$$R_i = \frac{\left[\frac{\int (Fx)_i\, dt}{m} + V_{ox})_i\right]\left[\left(\frac{\int (Fy)_i\, dt}{m} + V_{oy})_i\right) + \left[\left(\frac{\int (Fy)_i\, dt}{m} + V_{oy})_i\right)^2 + 2\, g\, y_i\right]^{\frac{1}{2}}\right]}{g} \qquad (17)$$

Equation 17 can be used to study the change in the takeoff forces required to increase the horizontal distance moved by the center of mass (Ramey 1973, 1982).

The three support phases of the triple jump, however, make it very difficult for researchers to test Ramey's theories. The reason for this difficulty is that it would take three force plates to collect force data on one complete performance of the triple jump, and for most triple jump research facilities this is not economically feasible. In addition, the subject would be required to contact consecutively each force plate with the entire foot. These limitations have caused studies which involve direct measurement of forces to be limited to jumping events that employ a single takeoff. Triple jump researchers who have measured takeoff forces have done so indirectly using cinematographic techniques.

Estimation Of Forces During Each Takeoff In The Triple Jump

After performing cinematographic analysis of twelve triple jumpers (some Olympic and world record holders), Dyson (1977) stated that he found forces of four times body weight during the hop and 3.8 times body weight during the step. Fukashiro et al. (1981) estimated the magnitude and direction of the resultant forces generated during each takeoff for three groups of triple jumpers of different ability levels. Using the impulse-momentum relationship as the basis for their calculations, they calculated mean horizontal and vertical forces were calculated using the following equations:

$$Fx = [(Vx2 - Vx1)/t]_m \quad \text{and} \quad Fy = [(Vy2 - Vy1)/t + g]\, m, \qquad (18)$$

where,

Fx = horizontal mean force

Fy = vertical mean force

m = body mass

g = acceleration due to gravity

t = takeoff time

Vx1 = horizontal velocity at touchdown

Vx2 = horizontal velocity at takeoff

Vy1 = vertical velocity at touchdown

Vy2 = vertical velocity at takeoff

Their calculations demonstrated that "There was no difference between the directions of the mean force vector in the hop and the step, but they were both more vertical than that for the jump" (p. 236). This resulted in greater conservation of the horizontal momentum during the hop and step takeoffs than during the jump takeoff. The length of vectors, i.e., the magnitude of force during each takeoff, was significantly different for each phase. The greatest force value was found in the step and the smallest in the hop.

In predicting the magnitude and direction of forces needed to obtain a jump of 18m, Fukashiro and Miyashita (1983) estimated the following force vectors: 36.4 N/kg and 101.2 degrees in the hop; 44.6 N/kg and 101.4 degrees in the step; and 42.9 N/kg and 100.7 in the jump. Their values were relative to body weight.

Hay and Miller (1985) also calculated mean horizontal and vertical forces at each takeoff using Equation 18. In their study, however, only the magnitudes of the forces were calculated. The mean values for the average horizontal and vertical forces made by twelve elite jumpers were:

	Average Horizontal Force (N)	**Average Vertical Force** (N)
HOP	-0.5	3.2
STEP	-0.8	3.8
JUMP	-0.6	3.7

These force values are the mean values for the average forces divided by the mean weight of the subjects. Hay's and Miller's force values were similar to those reported by both Dyson (1977) and Fukashiro et al. (1981).

Direct Measurement Of Forces During Each Takeoff In The Triple Jump

In an attempt to obtain direct force measurements, Ramey (1982) devised a procedure to collect triple jump force data using a single force plate. This procedure is illustrated in Figure 2.7. Ramey's procedure is explained below:

> In this instance the force platform was set flush with an approach runway and the subject, an experienced collegiate triple jumper, was directed to take three jumps from the force platform. First the subject was required to make a normal approach and execute the first support phase from the force platform. The first flight phase associated with this jump was to be done in the usual fashion which required that the landing area be modified to accept a vigorous one-legged landing without causing injury to the subject. Next the subject was directed to make a normal approach but to execute the first support and flight phases on the runway. These first phases were to be adjusted such that the end of the first flight phase would occur on the force platform. Then in the usual fashion the subject was to complete the second support phase on the force platform. Once again the second flight phase would be continued in the normal fashion. The previous modification to the landing area was kept in place so the subject could function as much as normal and yet not get injured. Finally, the subject was directed to initiate the first and second support and flight phases on the runway. These were to be adjusted such that the end of the second flight phase in this case was executed in the usual fashion with a landing occurring in a standard pit. (Ramey, 1982)

Using the single force plate technique for direct force measurements, Ramey found high values for the initial peak vertical force during the hop support phase. This value ranged from 7 to 12 times body weight (BW). In earlier studies, Ramey (1970) and Bosco et al. (1976) found that the

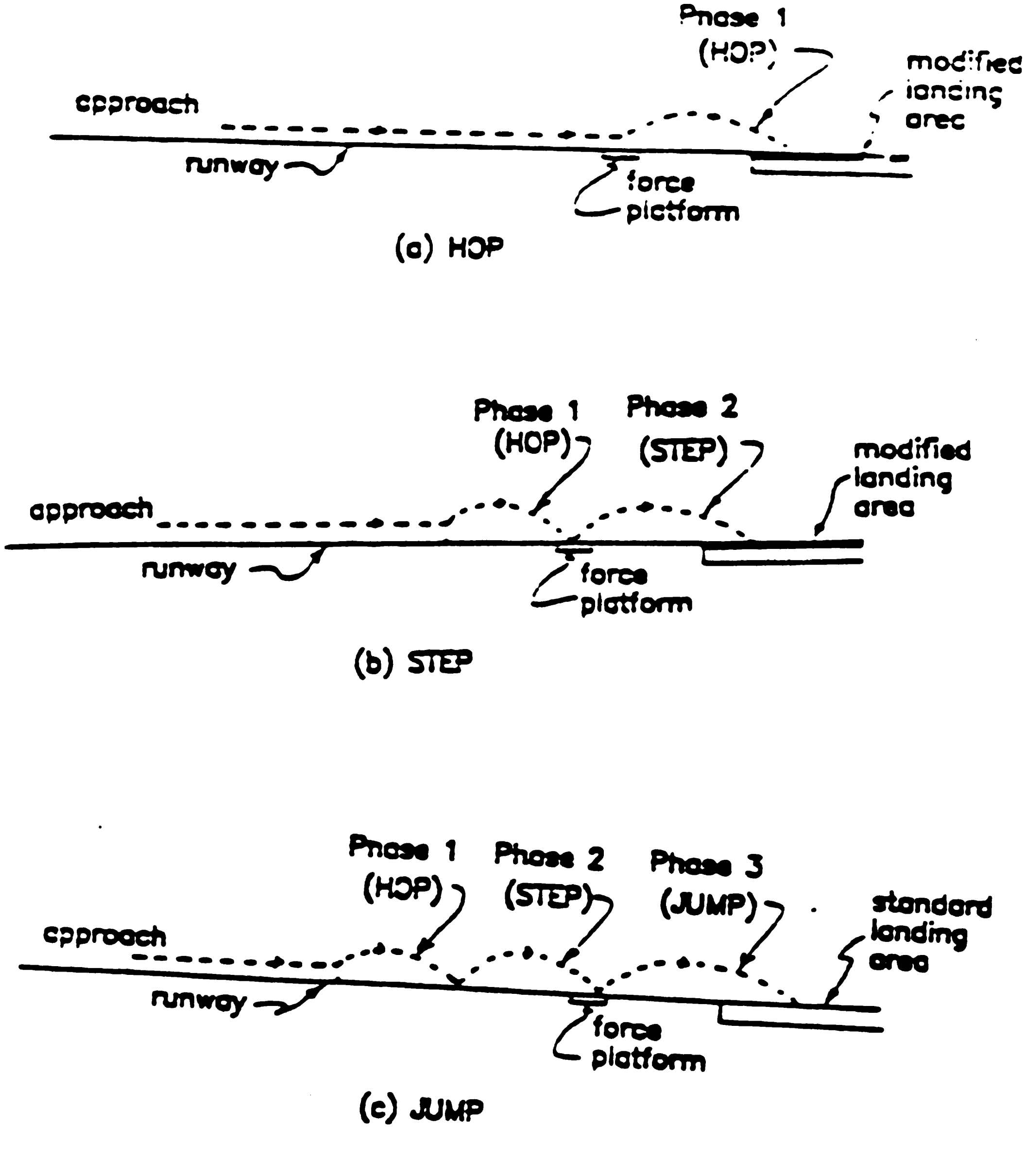

Figure 2.7 Ramey's method for direct measurement of forces during each support phase of the triple jump.

peak vertical forces for the long jump were 6BW to 7BW and acted over a relatively short period of time. Ramey (1985) found values ranging from 3.3BW to 5BW for the second peak in the vertical force in all three phases of the triple jump. This second peak covered a greater interval of time than the first peak. Second peak values for the long jump have been reported in excess of 4BW (Ramey, 1970; Bosco et al. 1976). Ramey's (1985) triple jump data led him to conclude, "the combination of very high initial peak forces acting over a short period of time and the large second peak forces acting over a relatively long time is likely to put a great deal of stress on the bones, ligaments, and muscles of the lower extremity" (p. 238).

Ramey (1985) also studied the changes in horizontal and vertical velocities that resulted from the forces applied during each contact phase. He found that "During each of the three phases of the triple jump, all subjects showed a decrease in horizontal velocity during contact with the ground, as determined from the net vertical impulse. These changes in velocity ranged from 0.49m/sec to 1.24m/sec, and were quite variable between phases and between subjects" (p. 238). The magnitude of Ramey's values was similar to that reported by Fukashiro et al. (1981) and Fukashiro and Miyashita (1983).

Ramey (1985) emphasized the variability that existed between subjects in terms of the changes in both horizontal and vertical velocities. He concluded, "It may be that mean data from a number of subjects conceals important differences between the way individuals execute the jump. The source of this individual variability may be due to differences in anatomical or muscular build, experience, training, or athletic ability, and be important in determining what the best triple jumping technique is for a given individual" (pp. 238-239).

Support Times

Besides being affected by the changes in takeoff forces, as Equation 15 showed, the change in linear momentum experienced by the jumper during each support phase is also affected by the duration of the support phase. Listed below are the mean support times for elite triple jumpers found by each researcher.

	HOP	STEP	JUMP
Bober (1974)	0.14s	0.18s	0.19s
Milburn (1979)	0.12s	0.15s	0.14s
Fukashiro et al. (1981)	0.12s	0.15s	0.16s
Hay and Miller (1985)	0.13s	0.17s	0.19s

In order to determine how changes in the duration of each phase of the triple jump affected the distance one can jump, researchers have looked at the correlation between duration of each support phase and total distance. Fukashiro et al. (1981) and Hay and Miller (1985) reported no correlation between support time in either the hop, step, or the jump and the total distance. Klissouras and Karpovich (1967) reported that they found no relationship between the duration of the hop support and the total distance of the triple jump. The findings by the above triple jump researchers are contrary to what has been reported by long jump and high jump researchers. They have consistently reported an inverse correlation between support time and total distance (Flynn, 1973; Hay, 1975; Klissouras & Karpovich, 1967). Klissouras and Karpovich speculated that there was no correlation between the duration of the hop support time and the total distance because of the influence of the next two support phases on the total distance.

CHAPTER 3

EXPERIMENTAL PROCEDURES

Population Target and Sample Selection

The population for this study were female interscholastic track and field athletes. Because of the time and effort necessary to learn to triple jump and the limited amount of training time available, random selection was not feasible. Therefore, eight interscholastic female track athletes were asked to volunteer for this study. The only restriction placed on their participation was that they must not have had prior training in the triple jump. This diminished the possibility that the subjects had a predisposition toward one style of arm swing over another when performing the hop takeoff. It was impossible to eliminate personal bias completely, however. Because of their previous training in the long jump and involvement in other sports that require jumping, most of the subjects brought with them a natural affinity toward the single arm swing.

Selected Research Design

The matched pairs design was used for this study as a means of decreasing variability between the jumpers. The subjects were matched in terms of their best long jump distance during the early part of the season. Using a flip of a coin, each individual in the pair was randomly assigned to learn either the single arm or double arm style of hop takeoff.

Triple Jump Training Procedures

After the subjects were matched and randomly assigned to learn either the single arm or double arm hop takeoff, they were trained for a period of one month to perform the triple jump using the appropriate style of hop arm swing. During each training session, the jumpers were divided into a single arm group and a double arm group. Both groups performed the same drills; however, the single arm group utilized a single arm swing while performing the drills, whereas the double arm group used a double arm swing.

Because each of the jumpers competed in various other events, their triple jump training was limited to a maximum of one hour per day four days per week. In exchange for use of the jumpers for this study, the researcher was asked by the head coach to teach the subjects to long jump as well. Therefore, approximately one half hour per day was devoted to long jump training while the other half hour was devoted to triple jump training.

Before the jumpers were given any instruction, they were shown films of triple jump performances to introduce them to the event. Through personal experience as a competitor, coach, and researcher, the investigator was able to point out examples of good triple jump technique. Besides demonstrating good triple jump technique, the triple jump films also introduced the subjects to the use of the arms in triple jumping.

Each training session attempted to develop the following skills: 1) basic running mechanics, 2) basic jumping mechanics, 3) proper approach run technique as determined by the researcher, and 4) proper triple jump technique. Each group used their appropriate assigned arm style when performing jumping drills.

Each jumper had to meet the following performance level before they were allowed to participate in the study: 1) they had to be able to consistently perform ten step approach triple jumps at 100% effort, 2) they had to use the proper hop arm style, and 3) they had to obtain an even ratio between the subdistances. For example, if their goal was to jump 24 feet, each phase must be 1/3 of the total distance or 8 feet.

Teaching Basic Running and Jumping Skills

A warmup routine called the Jumper's Routine was developed by the researcher in order to assist in teaching basic running and jumping skills. This routine incorporated a number of drills commonly used by sprint coaches and jump coaches. The following drills made up the Jumper's Routine.

1. Teaching basic running skills
   - arm form drill
   - high knee drill
   - fast leg drill
   - buildups on track

2. Teaching skills for the hop phase
   - rhythm and distance hopping on each leg using appropriate arm style

3. Teaching skills for the step phase
   bounding drill for rhythm and distance

4. Teaching skills for the step phase
   popup drill off each leg

5. Teaching hop-step-jump rhythm
   continuous hop-step-jump on grass.

Both groups performed the jumping drills using the appropriate arm style. The number of sets and repetitions for each drill was progressively increased during the training period to enhance the jumpers' general conditioning.

Teaching the Approach Run

During the initial stage of the approach run, the jumper attempted to maximize approach speed. During the latter stages, body configuration was manipulated in order to place the body in the optimal takeoff position. While preparing for takeoff, the jumper must attempt to conserve the speed that was acquired initially. As demonstrated by Campbell (1971), long jumpers who accelerated gradually during the approach run reached the takeoff board at a higher speed than jumpers who attempted to accelerate quickly at the start of the approach. The jumpers in the present study were trained to approach using the gradual acceleration technique. Regardless of the technique used during the approach run, approach speed will diminish somewhat during the latter stage as a result of takeoff preparatory movements (Carter, 1969). The gradual acceleration approach run technique was used in establishing the approach run distances for both the long jump and triple jump.

This technique was initially taught on the straightaway of the track. The jumpers were instructed to visualize themselves as a jet plane smoothly accelerating down the runway. The objective of this drill was to visualize oneself continuously accelerating until takeoff velocity was attained, i.e., maximum controllable speed. After maximum controllable speed was reached, the jumpers gradually decelerated until they stopped. A trained observer was positioned perpendicular to the straightaway. As the jumper accelerated along the track, the observer determined at which point on the runway the jumper reached maximum controllable speed. This point was noted but not disclosed to the jumpers. When the jumpers consistently reached "takeoff velocity" at the same place on the runway, the distance from the start of the approach to that point was measured. If the jumpers were inconsistent in their approach runs, they were given more basic drill work.

The approach distances established by using the above procedure ranged in length from 70 to 85 feet. These approach runs were used during long jump competition only. At no time during the one month training period were the jumpers allowed to triple jump using an approach of this length. The distance of the approach run for this study was set at ten steps. The purpose of limiting the length of the approach run was to enhance coordination and timing during the subsequent takeoff phases and reduce the risk of injury. During the instant between foot strike and takeoff, the jumper attempted to conserve the approach velocity developed on the runway while generating optimal vertical takeoff velocity. The forces that caused changes in velocity are ultimately a result of muscle actions associated with the movements of the body segments (Hay & Reid, 1982). The movements of the body segments must be precisely timed and coordinated in order to evoke the appropriate physiological responses that will allow the muscles to develop optimal forces. Forcing beginners to perform at 100% effort from a full run approach before they have mastered the mechanics of the takeoff will cause imprecise timing and imprecise coordination of the swinging segments during each support phase. The ten step approach, which was found to lie between 50%-60% of the jumper's full approach run distance, allowed the jumper to perform with confidence. The technique for the approach run remained the same, however: gradual acceleration.

Teaching Triple Jump Technique

Most of the training time was spent performing triple jumps into the landing pit from one step, four step, and eight step approaches. During the first week, all jumps were performed using a one step approach. The jumpers were instructed to triple jump to a marker which the researcher had placed on the landing pit. Initially, the marker was placed at a distance that each jumper could comfortably reach. The purpose of limiting the jumpers' efforts at this time was to allow them to practice technique rather than attaining distance. As their technique became more proficient, the total distance was lengthened.

The distances for the hop, step, and jump phases were also dictated by the researcher. As illustrated in Figure 3.1, flags of shoulder height were evenly spaced along the side of the landing area. For example, if the goal was to jump 24 feet, each flag was spaced 8 feet apart. This even spacing helped to reenforce the idea that each jump should be approximately of equal length. Once this skill was mastered, the total distance they were expected to jump was lengthened. The phase distances were lengthened accordingly so that each marker was spaced one third of the total distance.

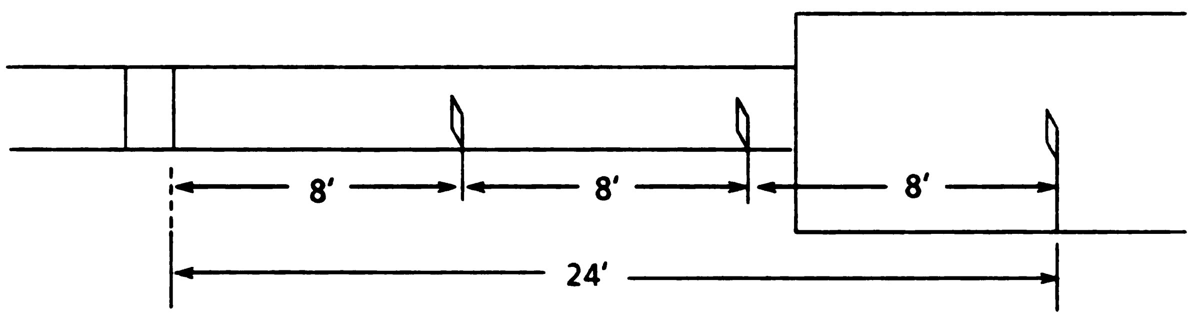

Figure 3.1 Placement of flags for even ratio practice jumps.

During the second week, the same drill was performed using a four step approach run. The four step approach in this drill represented the last four steps of a full approach. The emphasis, therefore, was placed on body position just before takeoff and accelerating into the takeoff.

By the third week, the jumpers' approach runs were lengthened to eight steps. At this stage of the learning progression, the jumpers competed in practice competitions at least twice a week. The longest jump in each flight was marked with a flag and the goal of each jumper was to surpass that distance. Flags designating phase distances were removed for these competitions. This allowed the jumpers to concentrate fully on acquiring maximum distance. Practice jumps using an even ratio, however, continued to be used during training sessions in order to reenforce the skill of triple jumping with even ratios.

Jumping Protocol

The site for this study was Eastern Michigan University's outdoor all weather tartan track. The women's triple jump takeoff board was 27 feet away from the pit, a distance that would cause most beginning high school female jumpers to struggle to reach the sand. In order to alleviate this problem, the women's takeoff board was ignored and the distance from the takeoff board to the beginning of the landing pit was adjusted so that the jumpers would comfortably reach the sand.

A road construction cone was substituted for the takeoff board and was placed 6.75m from the beginning of the landing pit. It was used only as a general reference mark as to where the first takeoff might begin. The jumpers were free to take off anywhere their final approach step landed. No fouls were recognized. This freed the jumpers from the inhibitions caused by the fear of fouling and enabled them to concentrate fully on acquiring maximum distance. An observer marked the point of the first takeoff for each jumper, and the total distance was measured from that point to the mark in the sand nearest to the point of takeoff.

The subjects dressed in loose fitting shorts that could be adjusted so that the hip joint would be visible. They also wore tank tops which allowed the shoulder, elbow, and wrist joints to be seen throughout the performance. The subjects were prepared for filming by placing contrasting joint markers on the lateral aspect of the right side of their bodies at the ankle, knee, hip, wrist, elbow, and shoulder joints. A self-adhesive dot was used to mark these joint centers which would be used during the film digitization process.

Each jumper performed four jumps using the appropriate style of hop takeoff. All jumps were measured using a 50 foot cloth tape measure. The jump covering the longest distance and displaying the appropriate form was used for data analysis.

Filming Procedures

Four LOCAM 16 mm high speed pin registered motion picture cameras were used to collect the data for this study. Three cameras were placed perpendicular to the field of view and recorded a sagittal view of the last five approach steps as well as the entire jump. The fourth camera recorded a frontal view of the entire approach and jump. All four cameras were set to operate at 100 fps with a shutter angle of 120 degrees and the actual filming speed was calibrated from timing boxes that were placed in the field of view. Each camera contained a 400 foot roll of Kodak Ektachrome Video News Film high speed 7250 tungsten film. This color film had an ASA of 400.

A meter stick, held in the center of the runway, was filmed by both the sagittal and frontal view cameras prior to filming the jumpers. From this horizontal reference measure, a linear multiplier scale factor was obtained. By multiplying the film distances by the scale factor, accurate conversion of film image distances to real life distances were made. In order to achieve consistent vertical orientation during film analysis, a pole was placed in the background as a vertical reference. Synchronized digital timing light boxes were placed in the field of view of all four camera for the purpose of film speed calibration and temporal analysis. Event markers were also filmed.

The camera setup is illustrated in Figure 3.2. As shown, each of the three side cameras were positioned 39.3m from the inner edge of the runway. This distance created an image size that was adequate for data acquisition. The distance between the first camera or "approach camera" and the middle or "hop camera" was 5.2m. The distance between the "hop camera" and the third or "step-jump" camera was 7m. With this arrangement, the last five approach steps plus the entire jump was recorded. The timing boxes were also visible in the field of view of each of the three cameras.

The positioning of the cameras caused the fields of view of each of the three cameras to overlap. The "approach camera" encompassed a field of view of 7.92m and recorded the last five approach steps plus part or all of the hop takeoff. The "hop camera" encompassed a field of view of 7.34m and recorded the entire hop phase plus part or all of the step takeoff. The "step-jump" camera encompassed a field of view of 7.64m and recorded the entire step and jump phases. All three cameras were leveled and fixed securely on a tripod 1.05m above the ground.

The fourth camera filmed a frontal view of the entire jump and was positioned 30m from the end of the landing pit. This camera placement was the maximum distance that could be attained in this setting. This camera was leveled and fixed securely on a tripod 1.11m above the ground. All filming was done with leveled and stationary cameras.

Projection and Digitizing System

Using an automated overhead Van Guard projection head, the film image was projected from above onto a drafting table. The projector was mounted on a fixed pole and was able to be electronically slid up and down the pole. By this means, the image size could be adjusted.

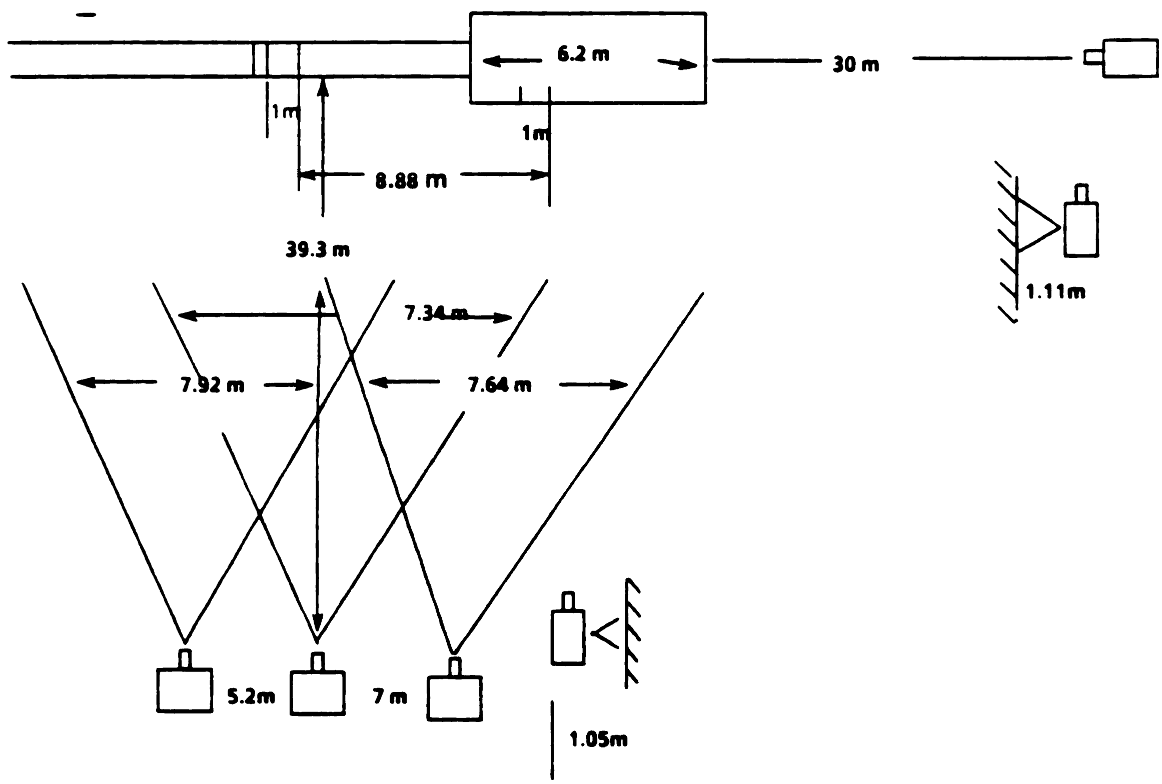

Figure 3.2. Camera Setup

Data generated by digitizing was obtained through the use of a Sonic Graf/Pen system. The Graf/Pen worked in conjunction with the drafting table which was equipped with two strip microphones located at right angles to one another. This digitizing system was interfaced with an IBM-PC computer on which was stored an interactive data acquisition computer program. The data acquisition program created data files which were stored on a floppy disk until these files were transferred to the Michigan State University Computer Center's Cyber 750 computer.

Besides the six joint centers previously mentioned, the right toe, seventh cervical vertebra, and the top of the head were also digitized. For this study, the hip joint was used as a substitute for the total body center of mass during data analysis. The data for the other digitized body points were stored for use in future studies.

Film Analysis Procedures

For data that was collected from the sagittal views, an orthogonal coordinate system was defined as follows: the Y axis was vertical with up as positive and down as negative; the X axis was parallel to the runway. The direction of the performance was positive and the direction opposite to the performance was negative. The coordinate system for data collected from the frontal view was determined as follows: in order to establish a reference point, a vertical line was dropped to a point midway between the hip joints. Inclinations to the left of that vertical line were negative and inclinations to the right of that vertical line were positive.

A Cyber 750 mainframe computer was used in analyzing the data. A FORTRAN program was used to analyze the takeoff data for the sagittal views. This program used a Butterworth filter to smooth the raw data points and then generated the kinematic variables necessary for this study.

The Quantification of Takeoff Data: Sagittal View

By definition, each support phase started the instant the jumper's support foot landed from the preceding flight phase and terminated the instant it left the takeoff surface. All kinematic takeoff data collected from the sagittal views were generated by the digitization procedure. The hip joint was digitized in every frame of film during each support phase. In addition, up to eight extra frames of film were digitized before touchdown and after takeoff. These extra frames allowed for accurate smoothing of the takeoff data.

The FORTRAN analysis program used the first central difference formula to compute the velocities of the hip joint over the entire support phase for each of the three support phases. From this velocity data, the intervening variables listed in Appendix A were calculated.

The average horizontal and vertical forces during each support phase were estimated using the impulse-momentum relationship. This was the method used by Fukashiro et al. (1981) described in Chapter 2. The force values for each group were also expressed as multiples of the mean body weight of the groups (BW). These BW values are the mean values for the average forces of each group divided by the mean weight of each group.

The Quantification of the Phase Distances

For this study, the phase distances (the hop distance, the step distance, and the jump distance) were measured manually from the film images. Each phase distance was determined by measuring the distance between the point of toeoff and the point of touchdown. These phase distances are shown in Figure 3.3. The image distances were then converted to real life distance by a linear multiplier conversion factor.

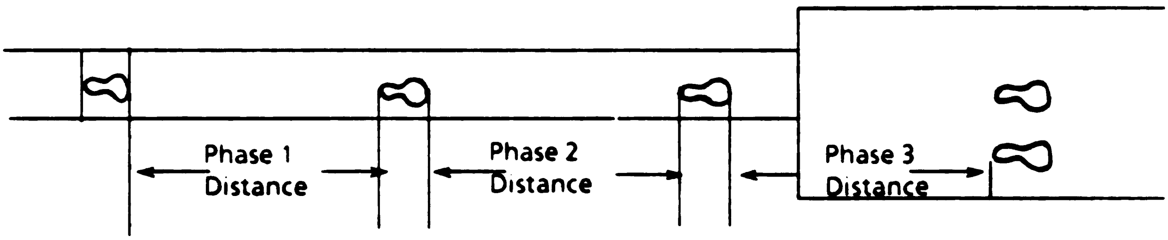

Figure 3.3. Measurement of phase distances.

The Quantification of Balance Data: Frontal and Sagittal Planes

Two measurements were taken to determine the amount of balance each jumper possessed at the last frame in which the foot was in contact with the ground. One measurement was taken in the sagittal plane and the other was taken in the frontal plane. They were as follows: 1) the horizontal distance in the sagittal plane between the takeoff toe and the hip joint and 2) the degree of trunk inclination from an imposed vertical reference line in the frontal plane. These measures were generated manually from film images and were taken at the instant of takeoff for each support phase. As shown in Figure 3.4, the horizontal toe to hip distance (d) was determined by measuring the horizontal distance between the toe of the takeoff foot and a vertical reference line drawn from the hip joint. As shown in Figure 3.5, trunk inclination was determined by measuring the angle between the midline of the trunk and the vertical reference line. The midline of the trunk was determined by drawing a line from a point midway between the hip joints to the xyphoid process. As previously described, deviations to the left of the vertical reference line with respect to the observer were given negative values and deviations to the right were given positive values.

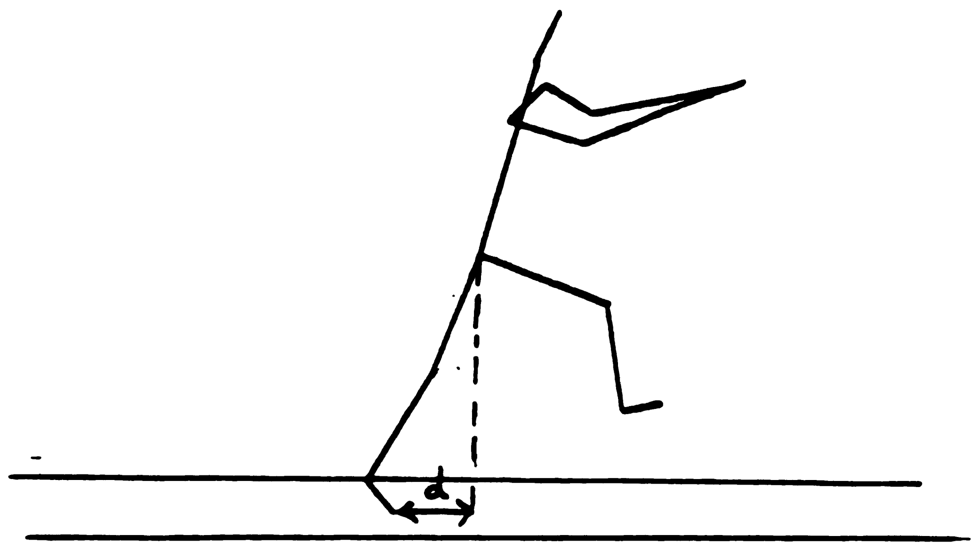

Figure 3.4. Measurement of horizontal toe to hip distance.

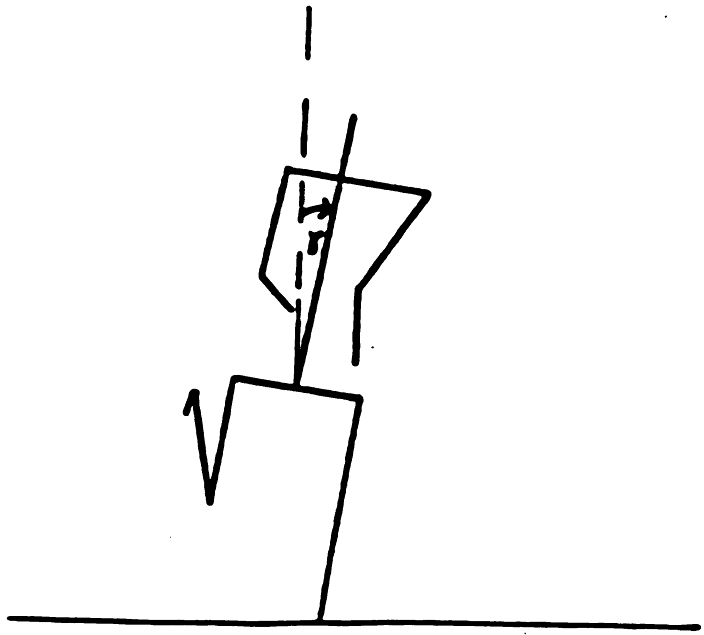

Figure 3.5. Measurement of trunk inclination.

CHAPTER 4

RESULTS AND DISCUSSION

The sections that follow report the results of a number of comparisons that were made using the findings for each of the intervening variables under consideration. The implications of these comparisons will be discussed in Chapter 5.

First, the mean performance of all jumpers in this study was compared to the performances of elite male triple jumpers as reported in published studies. These comparisons described the similarities and differences between the two skill levels on 1) the magnitude of the variable under consideration and 2) the way in which the variable was apportioned across phases. No hypotheses testing was performed on these comparisons.

Second, the mean phase values were compared for all jumpers in this study. Hypotheses testing was performed in order to determine if there was a statistically significant difference between the phase values, Ho (phases).

Third, the performance of the single arm and the double arm groups were compared for two purposes: 1) to determine if there was a statistically significant difference between the two groups on the intervening variable under consideration, Ho (groups) and 2) to determine if there was a statistically significant difference between the patterns of the single arm group and the double arm group with respect to the manner in which each intervening variable under consideration was apportioned across the three phases, Ho (pattern).

When the sample size is small, as was the case in this study, differences that are in reality very large may not appear to be statistically significant. In cases such as this, the researcher must realize that there might be a large difference between the groups on the variable under consideration even though the testing instrument was not sensitive enough to detect the difference. In order to maximize the power of the test statistic used in this study, the alpha level was set at .10. For a description of the statistical design and layout refer to APPENDIX B. ANOVA tables are listed in APPENDIX C.

Phase Distances

The means and standard deviations of the phase distances for the single arm and double arm groups are shown in Tables 4.1 and 4.2 respectively. The total distance jumped by each group as well as the percent contribution of each phase to the total distance were also included.

Table 4.1. Single Arm Group: Means and standard deviations and mean percent contributions of the phase distances.

SINGLE ARM	TOTAL	HOP	STEP	JUMP
Mean	8.46m	2.68m	2.20m	3.58m
S.D.		(.224)	(.23	(.240)
Contribution		31.7%	26.1%	42.4%

Table 4.2. **Double Arm Group: Means and standard deviations and mean percent contributions of the phase distances.**

DOUBLE ARM	TOTAL	HOP	STEP	JUMP
Mean	8.47m	2.71m	2.36m	3.40m
S.D.		(.260)	(.188)	(.094)
Contribution		31.9%	27.8%	40.3%

The mean percent contribution for all of the jumpers in the present study was 31.8%, 27.0%, and 41.4% for the hop, step, and jump distances respectively. The proportion these novice triple jumpers attributed to the hop and step phases were less than the 35% and 30% proportions for the hop and step phases Nett (1961) suggested (see Chapter 2). The jump phase distance was clearly longer than the hop and step distances. The observed differences between phases was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(2,6)= 49.44$, $p <.001$.

The mean total distance jumped by both groups was almost identical, 8.46m for the single arm group and 8.47m for the double arm group. Both groups were also similar on how they apportioned the phase distances. The mean percent contribution for the hop, step, and jump phases were 31.7%, 26.1%, 42.4% respectively for the single arm group and 31.9%, 27.8%, 40.3% respectively for the double arm group. These percentages illustrate that both groups followed a medium-short-long pattern. The pattern for both groups is shown in Figure 4.1.

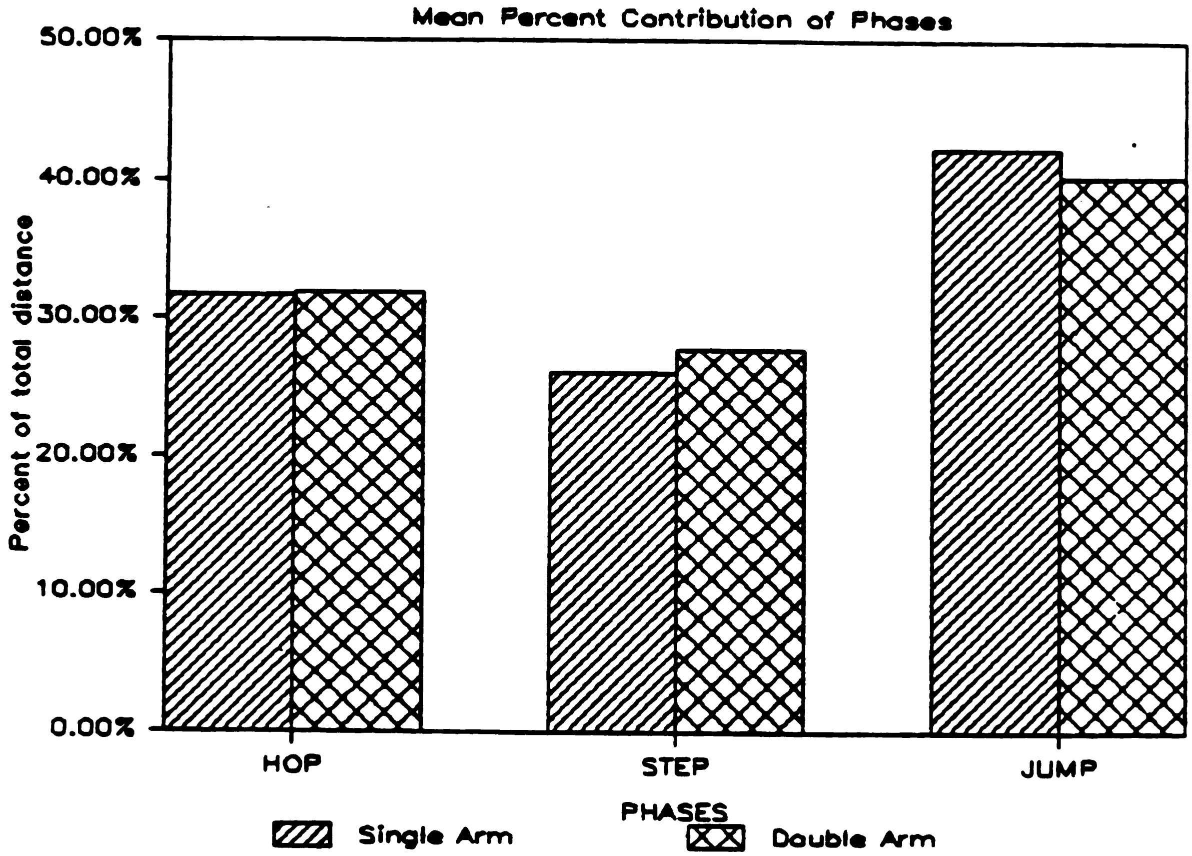

Figure 4.1. Mean percent contribution of phase distances.

These patterns illustrate that the mean percent contribution of the hop phases was almost identical, 31.7% for the single arm group and 31.9% for the double arm group. The double arm group placed slightly more emphasis on attaining distance in the step phase 27.8% as compared to 26.1% for the single arm group. The single arm group placed slightly more emphasis on the jump phase: 42.4% as compared to 40.3% for the double arm group. These patterns illustrate that the emphasis for both groups was placed on the jump phase. The difference between the patterns of the two groups, however, was small and lacked statistical significance ($p > .10$).

Even though both groups emphasized the jump distance over the hop and step distances, the correlation between jump distance and total distance was very low ($r = 0.09$, $p = .43$). There was, however, a significant correlation between the total distance and the hop distance ($r = .88$, $p = .005$). The four top performers in the study also had the four farthest hop distances.

Support Times

The means and standard deviations of the support times for the single arm and double arm groups are shown in Table 4.3. The mean support times for all jumpers in this study were 0.232s, 0.235s, and 0.251s for the hop, step, and jump respectively. This pattern of increasing duration of support time is similar to the elite jumpers discussed in Chapter 2. The mean support times for the five studies cited for elite jumpers were 0.130s, 0.154s, and 0.162s for the hop, step, and jump respectively. With the exception of Milburn's (1979) findings for elite triple jumpers, all other elite studies (Bober, 1974; Fukashiro et al., 1981; Hay & Miller, 1985) reported this short-medium-long pattern for support time. For this study, the observed difference in support times across phases was not statistically significant ($p > .10$). Duration of the novices' jump support phase, however, showed a high inverse correlation with total distance, $r = -0.78$, $p = .02$.

Table 4.3. Support times for single arm and double arm groups.

	HOP	STEP	JUMP
Single Arm	0.231s (.018)	0.206s (.031)	0.250s (.025)
Double Arm	0.233s (.017)	0.264s (.012)	0.251s (.016)

Mean (S.D.)

As shown, in Table 4.3, the support times for the single arm group were 0.231s, 0.206s and 0.250s for the hop, step, and jump respectively, an average of .229s per support phase. The support times for the double arm group were 0.233s, 0.264s, and 0.251s. They averaged .249s per support phase. This observed difference between groups on support time was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(1,3) = 17.11$, $p < .05$. This difference is a result of the large difference between the step support times for the two groups.

Figure 4.2 shows the pattern of the support times for both groups. These patterns demonstrated how each group distributed their support time across the three phases. As shown, the pattern for the single arm group was medium-short-long, whereas the pattern for the double arm group was short-long-medium. The hop and jump values for both groups were nearly identical. The step values, however, were markedly different .206s for the single arm group as compared to .235s for the double arm group. The difference between the two groups on the overall pattern of the support times was statistically significant ($F(2,6)= 3.46$ $p < .10$).

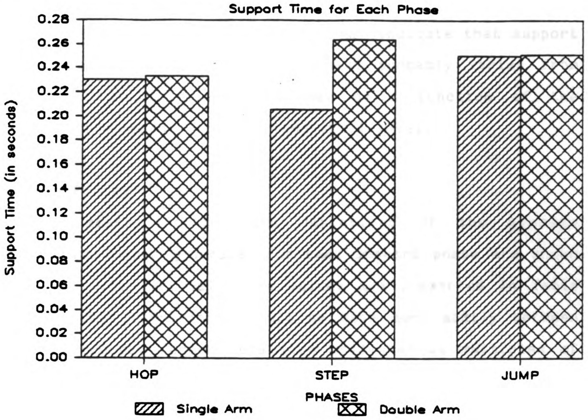

Figure 4.2. The pattern of the average support times for the single arm and double arm groups.

Three distinct patterns have been presented in this section, one for the elite studies cited, one for the single arm group, and one for the double arm group. The three support time patterns discussed above are presented in Table 4.4.

Table 4.4. The pattern of the average support times for novice and elite triple jumpers.

	HOP	STEP	JUMP
Elite triple jumpers	short	medium	long
Single Arm Group	medium	short	long
Double Arm Group	short	long	medium

These various support time patterns may indicate that support time duration for each support phase probably varies from individual to individual and may be a function of the individual's speed, strength, and skill level.

Takeoff Forces

The means and standard deviations of the average horizontal forces generated for each support phase are shown in Table 4.5. Vertical force values are presented in Table 4.6. So that comparisons could be made more easily between the two groups, forces were also presented as multiples of the mean body weight of the group (BW).

The average normalized horizontal forces (BW) for all jumpers in this study were -.016BW, .004BW, and -.14BW for the hop, step, and jump respectively. Negative signs for the force values in this study indicated that on the average the jumpers applied a braking force during that particular support phase, whereas positive force values indicated that on the average the jumpers exerted a propulsive force. As discussed in Chapter 2, Hay and Miller (1985) reported horizontal force values of -0.5BW, -0.8BW, and -0.6BW for elite male triple jumpers. The phase values for the elite jumpers indicated that on the average, a braking force was applied during each support phase. The braking forces generated by the elite triple jumpers were considerably greater than those generated by the novice jumpers. Unlike the elite performers, the average BW value for the novice jumpers during the step support phase was propulsive.

Table 4.5. Average horizontal takeoff forces in Newtons and multiples of mean group body weight.

	HOP	STEP	JUMP
Single Arm Group	-22.27N (138.50) -.043BW	121.40N (50.26) .234BW	-109.05N (44.18) -.210BW
Double Arm Group	5.26N (105.01) .011BW	-110.50N (73.75) -.227BW	-34.15N (132.50 -.070BW

Mean (S.D.)

Table 4.6. Average vertical takeoff forces in Newtons and multiples of mean group body weight.

	HOP	STEP	JUMP
Single Arm Group	822.65N (176.12) 1.59BW	709.84N (105.17) 1.37BW	793.55N (40.49) 1.53BW
Double Arm Group	814.69N (95.93) 1.68BW	676.81N (137.77) 1.39BW	689.50N (135.37) 1.42BW

Mean (S.D.)

The average normalized vertical BW values for all jumpers in this study were 1.64BW, 1.38BW, and 1.48BW for the hop, step, and jump respectively. These values follow a pattern of high-low-medium. Hay and Miller (1985) found vertical force values that were more than twice as high as the novices, 3.2BW, 3.8BW, and 3.7BW for the hop, step, and jump respectively. The pattern for the elites was low-high-medium. These BW patterns illustrated that the novices generated their highest vertical forces during the hop support phase and their lowest forces during the step support phase. The elite performers' highest vertical forces came during the step support phase and their lowest during the hop support phase. The difference between phases on average vertical force was not statistically significant ($p > .10$).

The single arm group generated average horizontal BW values of -.043BW, .234BW, and -.210BW for the hop, step, and jump respectively. The double arm group generated horizontal BW values of .011BW, -.227BW, and -.070BW. The average horizontal BW value across phases for the single arm group was -.006BW, whereas the average horizontal BW value for the double arm group was -.095BW. The observed difference between the groups on average horizontal force was not statistically significant ($p > .10$).

Figure 4.3 shows the graph of the horizontal BW values for both groups. The hop value of -.043BW for the single arm group indicated that on the average the single arm group applied a slight braking force, whereas the hop value of

.011BW for the double arm group indicated that on the average the double arm group applied a slight propulsive force. Both groups applied braking forces during the jump support phase. The braking force applied by the double arm group, however, was slightly higher than the braking force applied by single arm group, -.210BW to -.070BW. The step BW values were quite different. The single arm group applied a relatively high average propulsive force of .234BW whereas the double arm group applied a relatively high average braking force of .227BW. From the horizontal force data, it appears that the double arm style was slightly better for conserving horizontal momentum during the hop and jump support phases but during the step support phase the single arm style was considerably better. This observed difference in patterns between the two groups on average horizontal force was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(2,6) = 5.86$ $p < .05$.

The average vertical BW values found in this study during the hop, step, and jump support phases were 1.59BW, 1.37BW, and 1.53BW for the single arm group and 1.68BW, 1.39BW, and 1.42BW for the double arm group. The average vertical BW values across support phases for the two groups were identical, 1.50BW. The graph of the vertical BW values for both groups is shown in Figure 4.4.

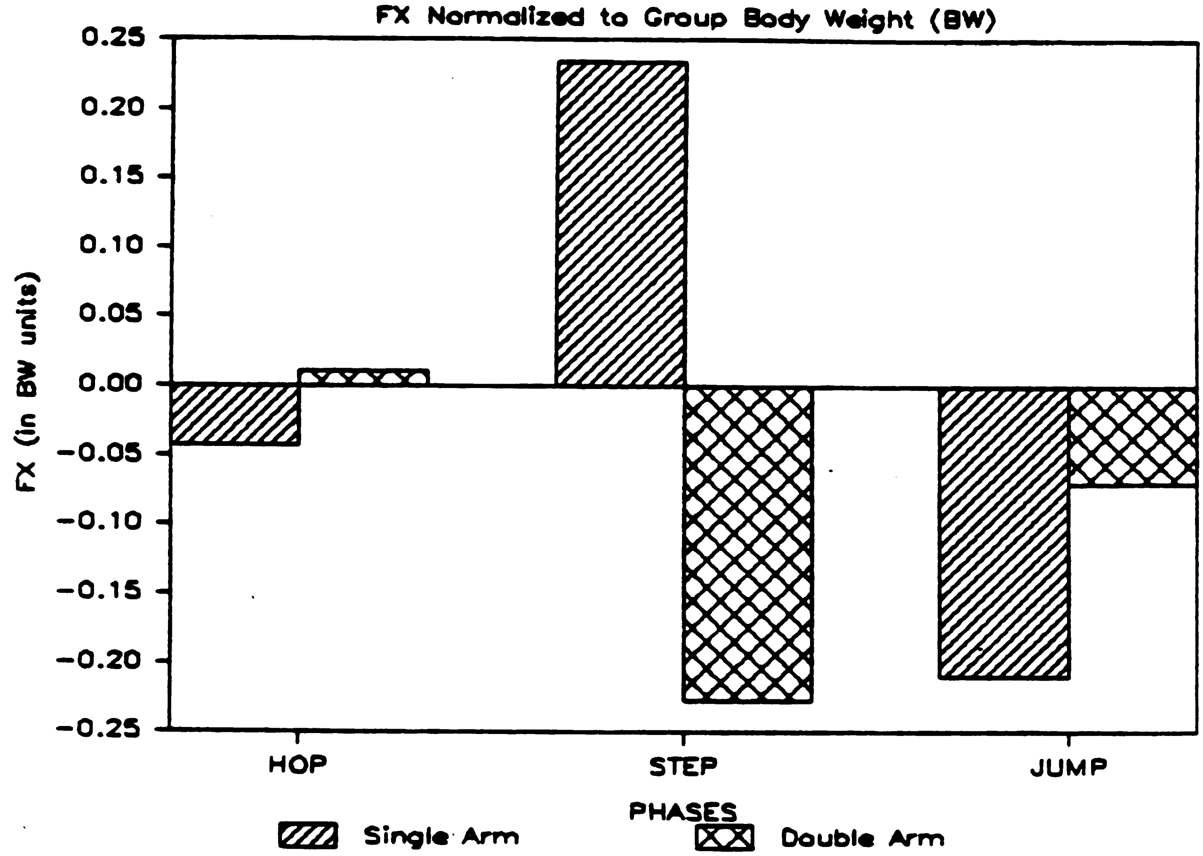

Figure 4.3. Horizontal BW force values for the single arm and double arm groups.

The pattern for the vertical BW values for both groups was similar, high-low-medium. On the average, the vertical forces generated during the hop and step takeoff phases were higher for the double arm group than for the single arm group. During the jump takeoff, however, the magnitude of the average vertical forces for the single arm group surpassed the double arm group. This observed difference in pattern for both groups on average vertical force was not statistically significant ($p > .10$).

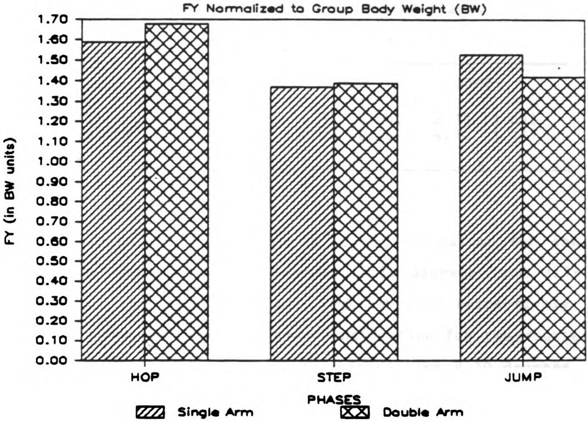

Figure 4.4. Vertical BW force values for the single arm and double arm groups.

Trunk Inclination in the Frontal Plane

The means and standard deviations of the degree of trunk inclination in the frontal plane for the single arm and double arm groups are shown in Table 4.7.

The averages for the degree of trunk inclination for all jumpers in this study were 2.63 degrees, 4.19 degrees, and 3.12 degrees, for the hop, step, and jump respectively. Positive values indicate that the jumpers were inclined to lean to their left in the frontal plane. The observed difference across phases for the novice was not statistically significant ($p > .10$).

Table 4.7. Means and standard deviations of the degree of trunk inclination in the frontal plane.

	HOP	STEP	JUMP
SINGLE ARM	1.75 (5.97)	4.38 (2.06)	2.13 (3.01)
DOUBLE ARM	3.50 (1.87)	4.00 (2.16)	4.10 (1.11)

Mean (S.D.)

The values for the degree of trunk inclination for the single arm group were 1.75 degrees, 4.38 degrees, and 2.13 degrees for the hop, step, and jump takeoffs respectively. The values for the degree of trunk inclination for the double arm group were 3.50 degrees, 4.00 degrees, and 4.10 degrees. The average inclination across phases for the single arm group was 2.75 degrees to their left while the double arm group inclined an average of 3.9 degrees to their left. This difference between the two groups on trunk inclination, however, was not statistically significant ($p > 10$).

There was also a lack of statistical difference between groups on the pattern of the degree of trunk inclination across phases ($p > .10$). In spite of the lack of statistical significance, the patterns are worth noting. These patterns are shown in Figure 4.5.

As shown in Figure 4.5, the degree of trunk inclination for the single arm group across phases followed a small-large-medium pattern, whereas the degree of trunk inclination for the double arm group was small-medium-large. The inclination values were positive for both groups during each of the three takeoffs. This indicated that both groups leaned to their left during each takeoff. The double arm group leaned more than the single arm group during the hop and step takeoffs, whereas the single arm group leaned more than the double arm group during the step takeoff. The degree of trunk inclination at the instant of step takeoff had a high and inverse correlation with both step distance $r = -.68$, $p = .05$ and with total distance, $r = -.62$, $p = .07$. This might indicate that the double arm swing is most important for "balance" during the difficult step takeoff.

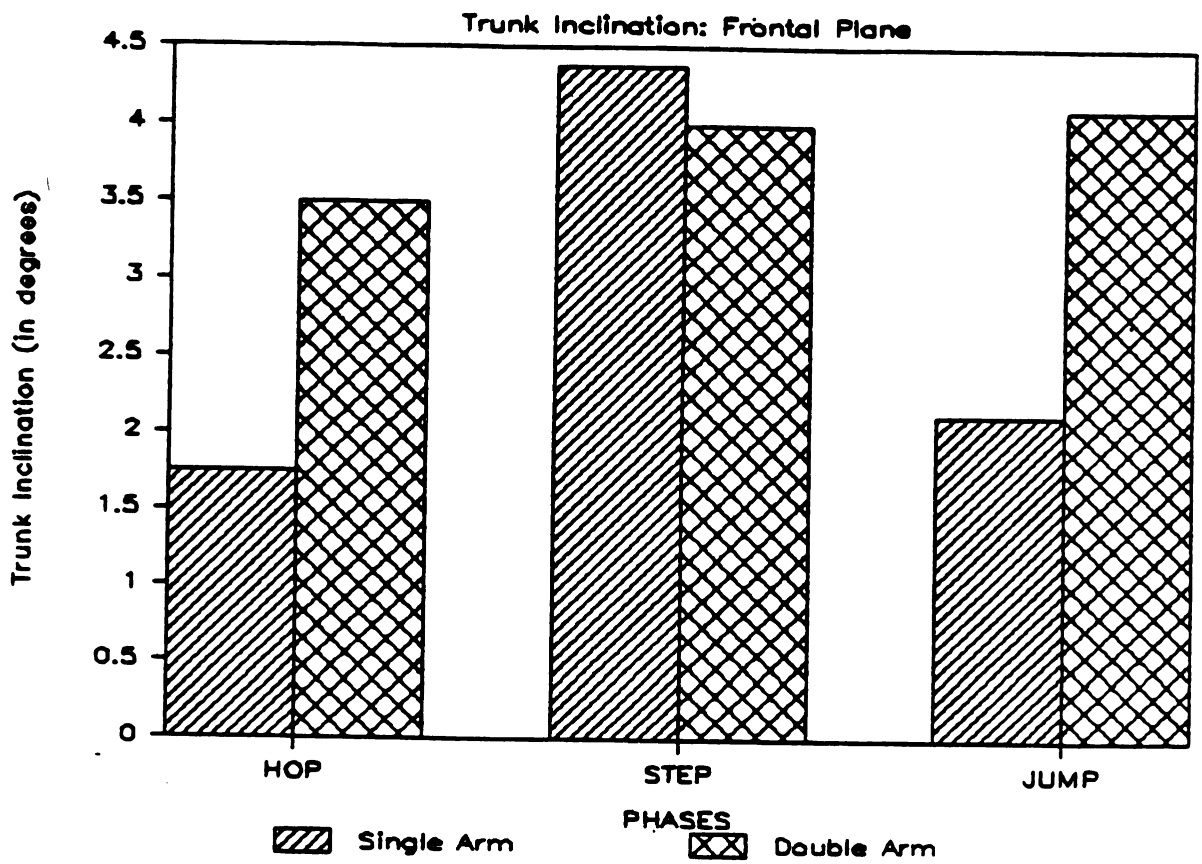

Figure 4.5. The pattern of the degree of trunk inclination for the single arm and double arm groups.

Toe to Hip Distance at Takeoff: Sagittal Plane

The means and standard deviations of the the horizontal distance between the toe and the hip joint at the instance of each takeoff are shown in Table 4.8. The average toe to hip distances in the sagittal plane for all jumpers in the study were .09m, .07m, and .03m for the hop, step, and jump takeoffs respectively. These values illustrated a large-medium-small pattern for the toe to hip distance across phases for all jumpers in the study. The positive sign of these data indicate that on the average for all jumpers in this study, the takeoff toe was behind the hip joint at the instant of each takeoff. The differences observed in the toe to hip distance across phases was not statistically significant ($p > .10$).

Table 4.8. Means and standard deviations of the horizontal toe to hip takeoff distance in the sagittal plane.

	HOP	STEP	JUMP
SINGLE ARM	0.19m (.185)	0.04m (.522)	-0.03m (.393)
DOUBLE ARM	-0.02m (.220)	0.10m (.432)	0.08m (.350)

Mean (S.D.)

In a study of highly skilled, average skilled, and less skilled triple jumpers, Milburn (1979) measured the horizontal distance between the iliac crest and the takeoff toe at the instant of each takeoff. The mean horizontal distances for the less skilled subjects were much greater than the distances found for the novices in this study. The distances he found were hop -0.42m, step -0.47m, and jump -0.46m. Negative measures in his study had the same meaning as positive measures in this study.

The toe to hip distances in the sagittal plane for the single arm group were 0.19m, 0.04m, and -0.03m for the hop, step, and jump respectively. The same distances for the double arm group were -0.02m, 0.10m and 0.08m. The single arm group averaged .067m for the three takeoffs whereas the double arm group averaged .053m. This difference between groups on toe to hip distance, however, was not statistically significant ($p > .10$). As can be determined from Table 4.8, on the average the single arm group's takeoff foot was planted behind the hip joint during the hop and step takeoffs and in front of the hip joint during the jump takeoff. This order was reversed for the double arm group. The observed difference in the two pattern of takeoff position was not significant ($p > .10$).

In spite of the lack of statistical significance ($p > .10$) for each of the three hypothesis being tested, the correlation data showed some interesting relationships. Table 4.9 illustrates the correlation between toe to hip takeoff distance at each takeoff and two distance variables, the distance jumped during that phase and the total distance covered.

Table 4.9. Correlation coefficients between toe to hip distance at each takeoff and selected phase distances.

Distances		HOP	STEP	JUMP	TOTAL
Toe to Hip Distance	vs	r = .17 p = .36			r = .41 p = .005
Toe to Hip Distance	vs		r = .53 p =.11		r = .86 p = .007
Toe to Hip Distance	vs			r = .21 p = .32	r = -.60 p = .007

n = 7

When correlating toe to hip distances at the instant of step takeoff with step distance, a moderate correlation of r = .53, p = .11 was found. Toe to hip distance at the step takeoff also correlated highly with the total distance jumped r = .86, p = .007. The toe to hip distance at the jump takeoff had a high but inverse correlation with total distance, r = -.60, p = .007.

Projection Angle

The means and standard deviations of the projection angles for the single arm and double arm groups are shown in Table 4.10. The average projection angles for all jumpers in this study were 17.81 degrees, 6.54 degrees, and 13.82 degrees for the hop, step, and jump takeoffs respectively. The observed difference between phases for projection angle was supported by statistical analysis. The difference in the projection angles across phases was found to be statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference $F(2,6) = 45.95$, $p < .001$.

Table 4.10. Means and standard deviations of the projection angles in degrees for the single arm and double arm groups.

	Hop	Step	Jump
Single Arm Group	16.12 (4.26)	5.81 (3.40)	15.29 (2.61)
Double Arm Group	19.50 (2.18)	7.27 (3.72)	12.34 (4.92)

Mean (S.D.)

As can be seen from the above data, the novice jumpers in this study had their highest projection angle at the hop takeoff and their lowest projection angle at the step takeoff. Their hop and jump projection angles were similar to reported findings for elite male triple jumpers but their step projection angle were considerably lower than their elite counterparts (Bober, 1974; Milburn, 1979; Fukashiro et al. 1981; Smith & Haven 1982; Susanka et al., 1984; Hay & Miller, 1985).

This finding of a higher hop projection angle than jump projection angle for the novices is contrary to the information that has been reported for elite triple jumpers. As discussed in Chapter 2, the jump projection angle for elite performers was usually higher than their hop and step projection angles. The novices' high hop projection angle may be an indication that they inadvertently tried to utilize long jump technique during the first takeoff of the triple jump. This could cause a higher hop projection angle.

The projection angles for the single arm group was 16.12 degrees, 5.81 degrees, and 15.29 degrees at the hop, step, and jump takeoffs respectively. The average projection angle for this group was 12.41 degrees. The projection angle for the double arm group was 19.50 degrees, 7.27 degrees, and 12.34 degrees. Their average projection angle was 13.04 degrees. The observed difference between the two groups on projection angle was not statistically significant ($p > .10$).

Figure 4.6 illustrates the pattern for the projection angle across phases for both groups. Both groups followed the same high-low-medium pattern. Inspection of the graph in Figure 4.6 shows that the hop and step projection angles were higher for the double arm group than for the single arm group. By the jump takeoff, however, the projection angle for the single arm group surpassed the projection angle of their counterparts. This deviation in pattern was not enough to result in a statistical difference at ($p > .10$).

As discussed in Chapter 2, the elite jumpers in the studies cited demonstrated a slightly different pattern than shown above. The pattern for their projection angles was medium-low-high Bober (1974), Milburn (1979), Fukashiro et al. (1981), Smith and Haven (1982), Susanka et al. (1984), and Hay and Miller (1985).

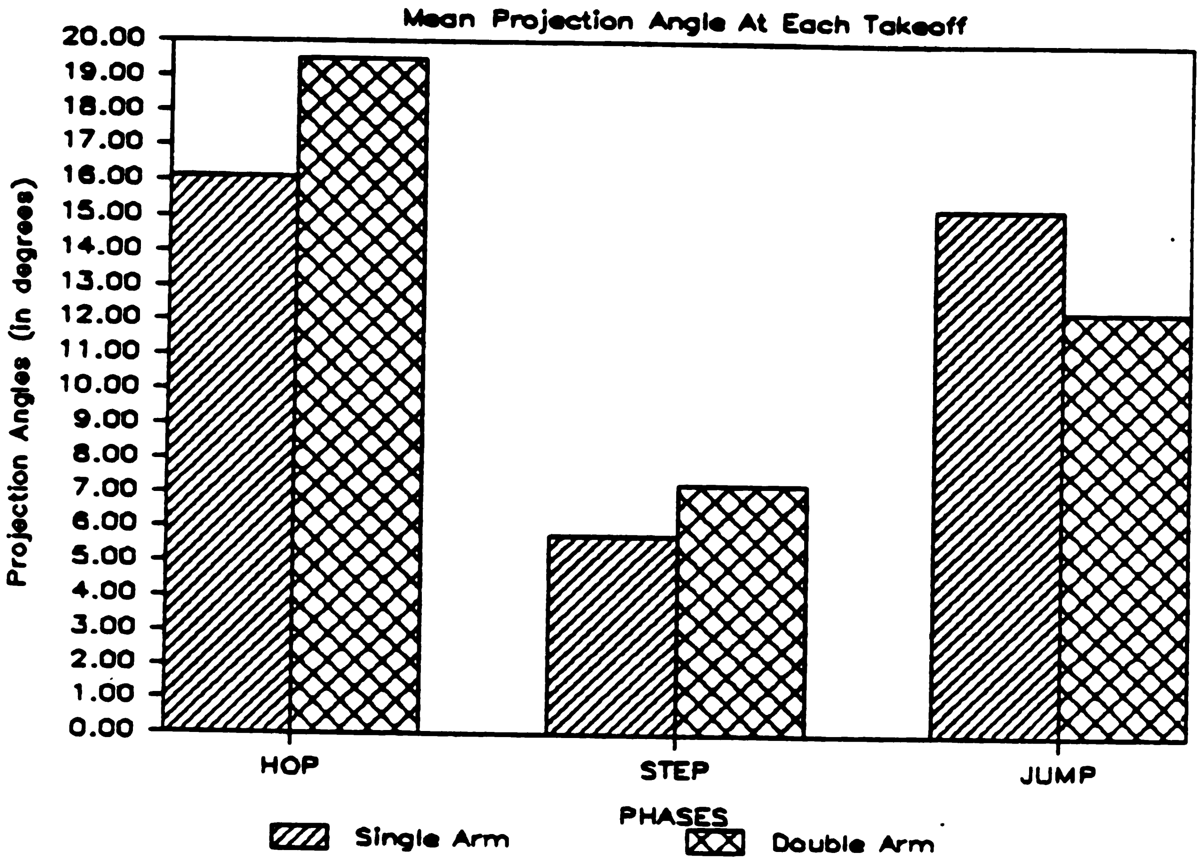

Figure 4.6. The pattern of the projection angles across phases for the single arm and double arm groups.

Horizontal Takeoff Velocities

The mean horizontal takeoff velocities of the hip joint for both the single arm and double arm groups are shown in Table 4.11. The mean horizontal takeoff velocities for all jumpers in this study were 4.43m/s, 4.15m/s, and 4.26m/s for the hop, step, and jump respectively. As expected for novice female triple jumpers, the horizontal takeoff velocities across phases were considerably less than those velocities reported for elite male triple jumpers by Bober (1974), Milburn (1979), Fukashiro et al. (1981), and Hay and Miller (1985). As discussed in Chapter 2, the mean horizontal takeoff velocities reported by these researchers were 8.77m/s, 7.76m/s, and 7.05m/s for the hop, step, and jump takeoffs respectively. The horizontal velocity values for the elite triple jumpers were nearly twice the horizontal velocity of the novice jumpers. The observed difference between phases for the novice jumpers in the present study was not statistically significant $p > .10$.

Table 4.11 Mean horizontal takeoff velocities for the single arm and double arm groups.

	HOP	STEP	JUMP
Single Arm	4.52m/s (.424)	4.17m/s (.768)	4.19m/s (.764)
Double Arm	4.33m/s (.152)	4.12m/s (.160)	4.32m/s (.377)

Mean (S.D.)

The horizontal takeoff velocities found in Table 4.11 for the single arm group were 4.52m/s, 4.17m/s, and 4.19m/s for the hop, step, and jump respectively. The horizontal takeoff velocities for the double arm group were 4.33m/s, 4.12m/s, and 4.32m/s. The average horizontal takeoff velocity across all three phases was similar for both groups, 4.29m/s for the single arm group and 4.26m/s for the double arm group. This observed similarity between groups is supported by statistical analysis. No statistically significant difference was found between the two groups on horizontal takeoff velocity ($p > .10$).

The mean horizontal takeoff velocities of the hip joint for both groups are contained in Figure 4.7. This graph illustrated how each group apportioned their horizontal velocity at each takeoff. As shown, the pattern for both groups was quite similar, fast-slow-medium. The horizontal takeoff velocity for the single arm group was slightly higher for the hop and step takeoffs but then dropped below the velocity for the double arm group for the jump takeoff. Milburn (1979) found the same fast-slow-medium pattern for the less skilled male jumpers he studied. Bober (1974), Milburn (1979), Fukashiro et al. (1981), and Hay and Miller (1985) all found a fast-medium-slow pattern in horizontal takeoff velocities for elite male triple jumpers.

Table 4.12 shows the percent change in horizontal takeoff velocity across the three phases for both groups. The horizontal takeoff velocity decreased slightly from the hop to the step for both groups: -7.72% for the single arm group and -4.92% for the double arm group. The horizontal velocity for the two groups increased, however, from the step takeoff to the jump takeoff. The double arm group increased 4.72% whereas the single arm group increased only .35%. It appeared that both groups either had difficulty generating horizontal velocity during the step support phase or that they saved their best effort for the final takeoff. The difference between the two groups on the pattern of their horizontal takeoff velocities was not statistically significant (p >.10).

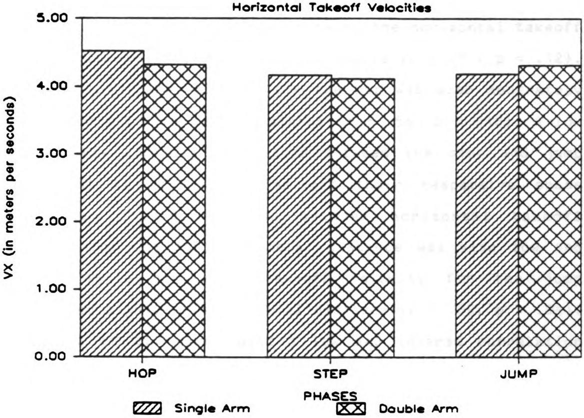

Figure 4.7. The change in horizontal velocity for the hip joint across phases for the single arm and double arm groups.

Table 4.12. The percent change in horizontal takeoff velocities for the single arm and double arm groups.

	HOP-STEP	STEP-JUMP
SINGLE ARM	-7.72%	.35%
DOUBLE ARM	-4.92%	4.72%

Evidence was found to claim associations between horizontal takeoff velocities for certain phases and certain phase distances. These data are shown in Table 4.13. A moderate correlation was found between the horizontal takeoff velocity for the hop and the hop distance (r = .51, p = .12). Horizontal takeoff velocity for the hop was also moderately correlated with the total distance (r = .55, p = .10). A low and inverse correlation existed between the step and jump horizontal takeoff velocities and their respective phase distances. The correlation between horizontal takeoff velocity for the step and total distance was also low and inverse while horizontal takeoff velocity for the jump correlated highly with the total distance (r = .69, p = .04). Fukashiro et al. also found a low and inverse correlation between horizontal takeoff velocity for the step and the step distance, but found a high correlation between the two jump parameters.

Table 4.13. Correlation coefficients between each horizontal takeoff velocity and each distance.

			HOP	STEP	JUMP
EACH DISTANCE	vs	Horizontal	.51	-.27	-.11
TOTAL DISTANCE		Velocity	.55	.11	.69

Vertical Takeoff Velocities

The means and standard deviations of the vertical takeoff velocities of the hip joint for both the single arm and double arm groups are shown in Table 4.14. The average vertical takeoff velocities for the jumpers in this study were 1.42m/s, 0.47m/s, and 1.04m/s for the hop, step, and jump respectively. The mean vertical takeoff velocities reported by the elite studies discussed in Chapter 2 (Bober, 1974; Milburn, 1979; Fukashiro et al., 1981; Hay & Miller 1985) were 2.18m/s, 1.67m/s, and 2.29m/s for the hop, step, and jump respectively. On the average, the novices generated a fast-slow-medium pattern across phases with the vertical velocity for the step being considerably less than for the hop and jump takeoffs. The observed difference between phases for the vertical takeoff velocity was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(2,6) = 41.02$ $p < .001$.

Table 4.14. Mean vertical takeoff velocities for the single arm and double arm groups.

	HOP	STEP	JUMP
SINGLE ARM	1.29m/s (.268)	0.41m/s (.249)	1.13m/s (.177)
DOUBLE ARM	1.54m/s (.193)	0.52m/s (.266)	0.94m/s (.387)

Mean (S.D.)

The vertical takeoff velocities for the single arm group was 1.29m/s, 0.41m/s, and 1.13m/s for the hop, step, and jump respectively. The vertical takeoff velocities for the double arm group were 1.54m/s, .52m/s, and .94m/s. The average vertical takeoff velocity across phases for the two groups was .93m/s and 1.00m/s for the single arm and double arm group respectively. This observed difference between groups for the vertical takeoff velocities was not statistically significant at p >.10.

As can be seen in Figure 4.8, the pattern followed by both groups' vertical takeoff velocities was fast-slow-medium. This was the same pattern found for their horizontal takeoff velocities. The average of the data reported by Bober (1974), Milburn (1979), and Fukashiro et al. (1981), and Hay and Miller (1985) shows that on the average the vertical velocity for elite male triple jumpers followed a medium-slow-fast pattern.

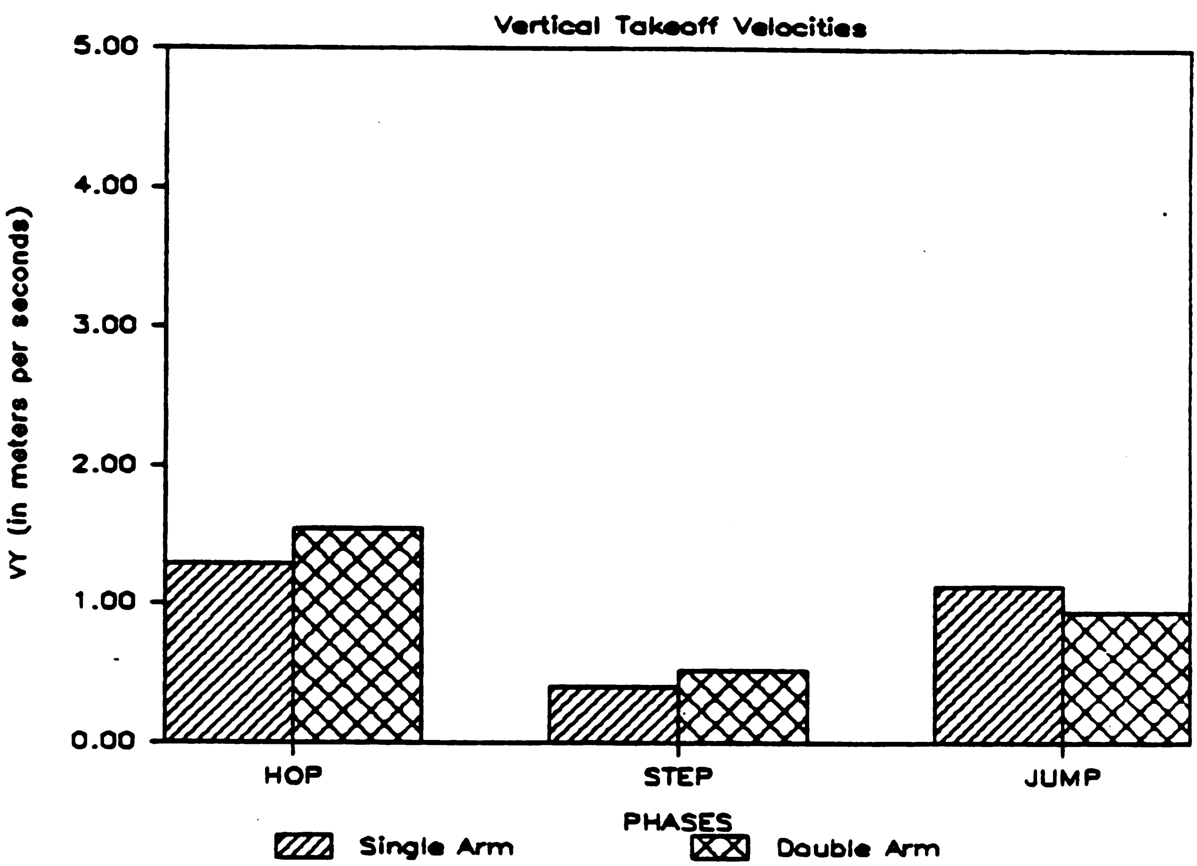

Figure 4.8. The change in vertical velocity for the hip joint across phases for the single arm and double arm groups.

Furthermore, the vertical takeoff velocities of the hop and jump were quite similar for both groups whereas the vertical takeoff velocity for the step for both groups was much smaller. The vertical velocity for the double arm group was higher than the single arm group for the first and second takeoffs but then dropped below the single arm group for the final takeoff. Statistically, there was no significant difference between groups for the pattern of their vertical takeoff velocities at $p > .10$.

Unlike the finding in this study for horizontal takeoff velocities, this study found insignificant correlations between vertical takeoff velocities and the respective phase distances. Fukashiro et al. (1981) found a moderate and positive correlation between vertical velocity at takeoff and the hop distance ($r = .52$, $p = .05$) and a high and positive correlation between vertical velocity at takeoff and the step distance ($r = .80$, $p = .001$).

Changes in Velocities During Each Support Phase

Figures 4.9 and 4.10, illustrate the change in horizontal and vertical velocities within the hop support phase of an 8.84m double arm jump and an 8.63m single arm jump, the best performances in their respective groups. The pattern of velocity changes during the hop support phase for these two jumpers were representative of the patterns observed for all jumpers in this study.

The pattern of the horizontal velocities for both groups of jumpers was quite similar. The horizontal velocity decreased during the first half of the support phase and increased during the second half. This is the same pattern reported by Fukashiro et al. (1981) for elite male Japanese triple jumpers for each of the three support phases. On the other hand, Fukashiro et al. reported that on the average for the elite male triple jumpers in their study, the vertical velocity generated during each support phase increased at an almost constant rate. As shown in Figures 4.9 and 4.10, the increase in vertical velocities for the two novice jumpers were not as steady. The pattern of the vertical velocities they generated during each support phase increased with an undulating pattern.

Because of the importance of conserving horizontal momentum throughout the performance, a closer look at how the velocities changed during each support phase is in order. Table 4.15 illustrates the average change in horizontal velocity from foot strike to toeoff for each support phase. On the average, the novice jumpers lost horizontal velocity during each support phase. The average velocity loss per support phase was -.055m/s, -.167m/s, and -.351m/s during the hop, step, and jump respectively. There was a greater lost in velocity with each successive support phase. Observed differences between phases, however, were not statistically significant at $p > .10$.

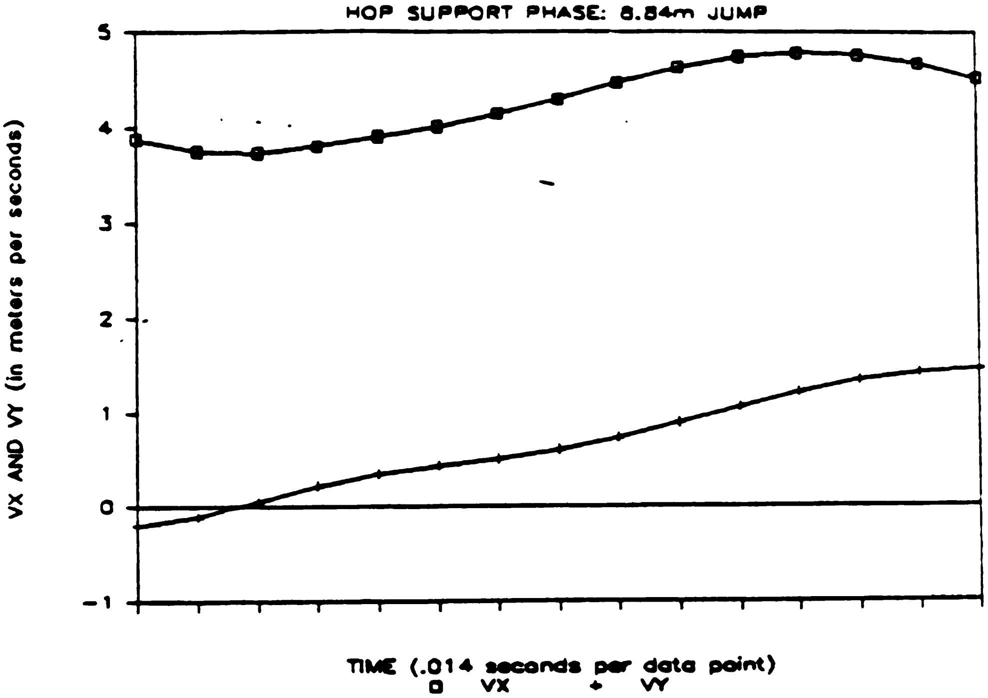

Figure 4.9. Graph of the horizontal and vertical velocities during the hop support phase for an 8.84m double arm performance.

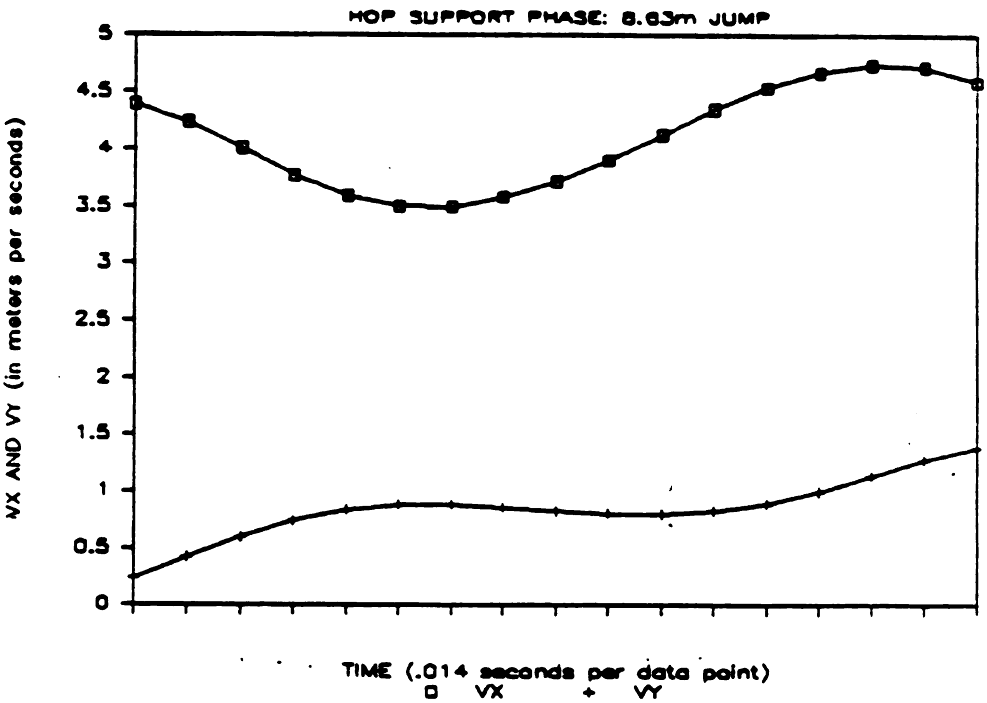

Figure 4.10. Graph of the horizontal and vertical velocities during the hop support phase for an 8.63m single arm performance.

Table 4.15. Means and standard deviations of the change in horizontal velocity during each support phase.

	HOP	STEP	JUMP
Single Arm Group	-.094m/s (.611)	.287m/s (.477)	-.518m/s (.213)
Double Arm Group	-.016m/s (.459)	-.621m/s (.439)	-.183m/s (.635)

Mean (S.D.)

The single arm group had a greater loss in horizontal velocity during the hop and jump support phases than did the double arm group. During the step support phase the horizontal velocity for the single arm group increased. In contrast, the double arm group had their biggest loss in horizontal velocity during the step support phase. The hop support phase allowed the smallest horizontal velocity loss for both groups and the change in horizontal velocity during this support phase was moderately correlated with total distance, $r = .55$, $p = .12$. The difference between groups on the pattern of the changes in horizontal velocity was not statistically significant ($p > .10$).

Chapter 5

SUMMARY AND CONCLUSIONS

Summary of Procedures

The purpose of this study was twofold. First, this study compared the performance of novice triple jumpers to published findings of elite male triple jumpers on many of the variables that have been determined to be important in triple jump performance. This will increase the general pool of research knowledge in the area of triple jump training. Second, this study determined the effects of the single arm style and the parallel double arm style of takeoff on novice triple jump performance. More specifically, the second part of this study included an investigation of the effects of arm style on the intervening mechanical variables as well as the total distance jumped.

The population for this study were female interscholastic track and field athletes. Eight subjects originally volunteered to participate in this study. One, however, dropped out before the data were collected. The subjects had had no prior training in the triple jump. They were randomly assigned to two groups and matched on their best long jump distance. One group was trained to triple jump performing each takeoff using a single arm swing while the other was trained to triple jump using the parallel double arm swing. The subjects were trained for one month and the training time for the triple jump was limited to one half hour per day four days per week. A number of training procedures were devised by the researcher in order to facilitate the training of the subjects.

The subjects were prepared for filming by placing joint markers on their joint centers. Only the right side of their bodies were marked. These joint markers served as reference markers for digitizing. Four LOCAM 16mm high speed pin registered motion picture cameras were used to collect the data for this study. Three cameras were placed perpendicular to the field of view and recorded a sagittal view of the last five approach steps as well as the entire jump. The fourth camera recorded a frontal view of the entire approach and jump. All four cameras were set to operate at 100 fps and the actual filming speed was calibrated from timing boxes that were placed in the field of view. Each camera contained a 400 foot roll of Kodak Ektachrome Video News Film high speed 7250 tungsten film. This color film had an ASA of 400.

The film was digitized using a Sonic Graf/Pen system. An automated Van Guard projection head projected the film image from above onto a drafting table equipped with two strip microphones located at right angles to one another. This digitizing system was interfaced with an IBM-PC computer on which was stored an interactive data acquisition computer program. The Cyber 750 mainframe computer located in the computer center at Michigan State University was used in analyzing the data. A FORTRAN program was used to analyze the takeoff data for the sagittal views. The takeoff data for the frontal view was analyzed using manual techniques.

Summary of Statistical Findings

Three hypotheses were tested in this study. The first, Ho(phases), was tested for each of the intervening variables under consideration in order to determine if there was a statistically significant different ($p < .01$) between the three phases of the triple jump. The next two hypotheses, Ho (groups) and Ho(patterns), were tested for each of the intervening variables in order to determine if there were any statistically significant differences ($p < .10$) between the single arm and double arm groups on 1) the magnitude of the variable, Ho(groups) and 2) the pattern followed by the variable across the three phases, Ho(pattern). The three hypotheses tested were as follows:

Ho(phases) There is no difference between the three phases with respect to the intervening variables under consideration when examining triple jumpers regardless of the type of arm style utilized.

Ho(groups) There is no difference between triple jumpers who use the single arm and double arm styles of takeoff on the total distance jumper or any of the intervening variables under consideration.

Ho(patterns) There is no difference between the pattern of the single arm group and double arm group with respect to the way each intervening variable under consideration is apportioned across the three phases.

The split plot design was used for statistical analysis. The three hypotheses were tested using the appropriate F-tests and rejection was set at $p > .10$. ANOVA tables are listed in APPENDIX C.

This study found that there was no statistically significant difference ($p > .10$) between the single arm and the double arm groups for any of the intervening variables under consideration with the exception of support times and horizontal takeoff forces. A statistically significant difference between the two groups was found for the way in which horizontal takeoff forces were apportioned across the three phases (Ho(patterns), $F(2,6) = 5.86$, $p > .05$). The two groups also differed on both the magnitude of their support times (Ho(groups), $F(1,3) = 17.11$, $p > .05$) and the way in which they apportioned their support times across the three phases (Ho(patterns), $F(2,6) = 3.46$, $p > .10$).

When the values for all jumpers were pooled together, however, significant differences were found between the three phases. Convincing evidence was found to reject Ho(phases) for three of the intervening variables under consideration, vertical takeoff velocities ($F(2,6) = 41.02$, $p > .001$), phase distances ($F(2,6) = 49.44$, $p > .001$), and projection angles ($F(2,6) = 45.95$, $p > .001$).

Summary of Findings for Phase Distances

1. The total distance jumped by the single arm and the double arm groups was almost identical, 8.46m for the single arm group and 8.47m for the double arm group.

2. On the average, for all jumpers in this study, the jump distance was the greatest contributor to the total distance. The mean percent contribution of the phase distances were 31.8%, 27.0%, and 41.4% for the hop, step, and jump distances respectively. The

difference between phases was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(2,6) = 49.44$, $p < .001$.

3. In spite of the emphasis on the jump distance, the correlation between jump distance and total distance was very low $r=0.09$, $p=.43$. There was, however, a significant correlation between the total distance and the hop distance $r=.88$, $p=.005$.

4. The single arm and the double arm groups were similar in the manner in which they apportioned the hop, step, and jump distances, 31.7%, 26.1%, and 42.4% for the single arm group and 31.9%, 27.8%, and 40.3% for the double arm group. The difference between the patterns of the two groups lacked statistical significance ($p > .10$).

Summary of Findings for Support Times

5. The average support times for the jumpers in this study were 0.232s, 0.235s, and 0.251s for the hop, step, and jump respectively. The observed difference in support times across phases was not statistically significant ($p > .10$).

6. Support times for the novices were considerably greater than the support time values reported for elite male triple jumpers. The shorter support times for the elite triple jumpers was probably a result of their greater approach speed. The patterns for both skill levels, however, were identical, short-medium-long.

7. There was a high inverse correlation of $r = -0.78$, $p=.02$ between the duration of the jump support phase and the total distance.

8. The duration of the hop and jump support phases for the single arm and double arm groups were similar. The step support phase for the double arm group, however, was considerably longer than that of the single arm group. The observed difference between groups was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(1,3) = 17.11$ $p < .05$. There was also a significant difference between the patterns of the two groups $(F2,6) = 3.46$, $p < .10$).

Summary of Findings for Support Forces

9. Both the single arm and double arm groups applied their greatest horizontal forces during the step support phase. On the average, the single arm group applied propulsive forces whereas the double arm group applied braking forces. Both groups applied their greatest vertical forces during the hop support phase. Published research on elite male triple jumpers revealed that these male triple jumpers applied their greatest horizontal and vertical forces during the step support phase.

10. There was no significant difference ($p > .10$) between phases on either horizontal or vertical force.

11. There was no significant difference ($p > .10$) between the single arm group or the double arm group on the magnitude of either their horizontal or vertical forces. In fact, the average vertical BW values across phases for both groups were identical, 1.50 BW.

12. The patterns for the two groups on vertical BW values were similar, high-low-medium. The patterns for the two groups on the horizontal BW values were different. The pattern for the single arm group was low braking-high propulsive-medium braking for the hop, step, and jump support phases respectively. The pattern for the double arm group was low propulsive-high braking-medium braking. The observed difference between patterns on horizontal BW was significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(2,6) = 5.86$, $p < .05$.

Summary of Findings for Trunk Inclinations

13. The average degree of trunk inclination in the frontal plane for all jumpers in this study was small 2.63 degrees, 4.19 degrees, and 3.12 degrees for the hop, step, and jump takeoffs respectively. On the average, jumpers in this study tended to lean to the right at the instant of takeoff.

14. There was no significant difference, $p > .10$ between phases on degree of trunk inclination.

15. The double arm group leaned more than the single arm group during the hop and jump takeoffs but less during the step takeoff. There was no significant difference ($p > .10$) between groups on degree of trunk inclination.

16. The degree of trunk inclination at the instant of step takeoff had a high and inverse correlation with both step distance $r = -.68$, $p = .05$ and total distance $r = -.62$, $p = .07$.

17. There was no significant difference ($p > .10$) between patterns on the degree of trunk inclination.

Summary of Findings for Toe to Hip Joint Distances

18. There was no significant difference, $p > .10$ between phases, groups, or patterns on the horizontal distance between the toe and hip joint.

19. Toe to hip distance at the instant of the step takeoff had a positive correlation with step distance, $r = .54$, $p = .12$ and with total distance $r = .86$, $p = .007$. Toe to hip distance at the instant of jump takeoff had a high but inverse correlation with total distance $r = -.60$, $p = .007$.

Summary of Findings for Projection Angles

20. On the average, the projection angles for the hop takeoff for all jumpers in this study were higher than the projection angles for both the jump and step takeoffs. These findings were contrary to findings reported in studies of elite triple jumpers. In the elite studies, the jump projection angle was higher than the hop and step projection angles.

21. The novice's step projection angle was considerably lower than their hop and jump projection angles. It was also considerably lower than step projection angles reported for elite triple jumpers. The observed difference across phases for the novice triple jumpers was statistically significant ($p < .10$). The computed F value, however, showed more convincing evidence of statistically significant difference, $F(2,6) = 45.95$, $p < .001$.

22. There was no significant difference ($p > .10$) between groups on projection angle.

23. Both the single arm group and the double arm group produced a high-low-medium pattern as compared to the medium-low-high pattern reported for elite male triple jumpers. The observed difference between patterns for the jumpers in this study was not statistically significant ($p > .10$). Reported findings for elite triple jumpers show a slightly different pattern than the novices in this study.

The pattern of their projection angles was medium-low-high.

Summary of Findings for Takeoff Velocities

24. As expected for novice female triple jumpers, the horizontal and vertical takeoff velocities were considerably less than those reported for elite male triple jumpers.

25. The horizontal takeoff velocities for the jumpers in this study were 4.43m/s, 4.15m/s, and 4.26m/s for the hop, step, and jump respectively. The vertical takeoff velocities for the jumpers in this study were 1.42m/s, 0.47m/s, and 1.04m/s for the hop, step, and jump respectively. There was no significant difference ($p \geq .10$) between phases on horizontal takeoff velocities, but there was a significant difference between phases on vertical takeoff velocities $F(2,6) = 41.02$, $p < .001$.

26. There was no significant difference between the single arm group and the double arm group on either horizontal or vertical takeoff velocities ($p > .10$).

27. Both groups followed a fast-slow-medium pattern across phases for both the horizontal and vertical takeoff velocities. Studies for elite male triple jumpers show that they followed a fast-medium-slow pattern for vertical takeoff velocities and a fast-medium-slow pattern for horizontal takeoff velocities.

28. The general pattern of the horizontal and vertical velocities during each support phase for the jumpers in this study was similar for both groups. The horizontal velocity decreased during the first half of each takeoff and increased during the second half. Their vertical velocities increased in an undulating pattern.

Conclusions

The findings in this study indicated that novices can learn to triple jump using either the single arm or the double arm style within a very short period of time. Because most people have a natural bias toward the single arm swing, the single arm group needed very little instruction in order to learn this style of takeoff. This natural affinity toward the single arm swing allowed the single armers more time to concentrate on acquiring general triple jump skills. On the other hand, the double arm group had to work diligently in order to become proficient at swinging both arms during each takeoff. Within the one month time limit, however, the double arm group was able to become proficient at this technique. The fact that the total distance jumped by both groups was nearly identical indicated that, in spite of the difficulties the double arm group experienced learning the technique, they were eventually able to attain a level of proficiency equal to that of the single arm group. The double arm group's ability to equal the proficiency of the single arm group with minimum training time suggested that given more training they might be able to surpass the performance of their single arm counterparts.

As described in Chapter 3, both groups were trained to perform with evenly proportioned phase distances. The objective of this training procedure was to instill in them the importance of not over emphasizing one phase to the detriment of another. In reality, phase distances are rarely if ever equal. This was also true for the jumpers in this study. The contributions of their phase distances were 31.8%, 27%, and 41.4% for the hop, step, and jump distances respectively. In essence, the triple jumpers in this study seemed to gravitate toward phase distances that were appropriate for their strength, speed, and skill level.

The medium-short-long pattern used by the jumpers in this study resembled the Polish style of triple jumping. A jump contribution of 41.4%, however, far exceeded any reported findings for Polish style elite triple jumpers. By using data gathered by Hay and Miller (1985), Ecker (1987) determined the mean jump contribution for the 1984 Olympic finalists who used the Polish style was 36.3%.

In spite of over emphasizing the jump distance, the 31.8% and 27% contribution of the hop and step distances respectively showed that the novices' techniques reached a fairly high level of proficiency. By comparison, the hop contribution for the 1984 Olympic finalists was 36.4% and 34.2% for the Polish style and the Russian style jumpers respectively. It was also of interest to note that for the jumpers in this study, there was a positive correlation of r=.88, p=.005 between the hop distance and the total distance. This high correlation probably indicated that it was easier to conserve momentum during the step and jump takeoffs if the jumper performed well during the first takeoff. In other words, it is difficult to make up for a poor first takeoff during the second and third takeoffs. It should not be assumed, however, that if the novices increased their 31.8% hop contribution to 36.4% their total distance would increase accordingly. Increasing the length of the hop would also increase the stress placed on the jumper upon landing. If their strength and skill level remained the same, it is unlikely that novice jumpers could rebound from the shock of landing from a long hop.

Coaches generally acknowledge that achieving a long step distance in comparison to the hop and jump distance is very difficult regardless of skill level. It usually takes years of training in order to develop the muscular strength, power, and coordination needed to make an efficient transition from the hop landing to the step takeoff. The mean step contribution for the twelve finalists in the 1984 Olympic Games was 29.4% (Hay & Miller, 1985). The average contribution of 27% for the novice jumpers in this study was quite good by comparison, and was certainly better than would have been expected for beginning triple jumpers. Their proficiency in the step phase was probably the result of two training procedures used in this study: 1) forcing them to perform training jumps using evenly proportioned phase distances, and 2) limiting their approach run to only 10 steps.

The step contribution of 27.8% for the double arm group was somewhat better than the 26.1% step contribution for the single arm group. These findings might reflect an advantage in using the double arm swing during this most difficult phase. This advantage was supported by the findings for the intervening variables. The magnitude of both the average horizontal and vertical forces applied during the step support phase was greater for the single arm group. The double arm group, however, applied the forces much longer than the single arm group, .264s as compared to .206s. Therefore, in spite of applying less force, the double arm group was able to apply greater average impulses. The horizontal impulse values applied during the step support phase were 25.01Ns for the single arm group and -29.17Ns for the double arm group. The vertical impulse values were 146.23Ns for the single arm group and 178.68Ns for the double arm group. These impulse values indicated that the real advantage of the double arm swing may be in allowing the jumpers to apply greater impulses during the step support phase, especially vertical impulse.

For novice triple jumpers, improvement in step distance will probably come with an improvement in vertical force application during the step support phase and overall strength development. The jumpers in this study were able to apply relatively large horizontal forces during the step support phase when compared to the horizontal forces found for their hop and jump support phases. However, when compared to their hop and jump vertical takeoff forces, their step vertical takeoff force was relatively small. One manner in which to increase the jumpers' ability to generate vertical takeoff forces is to develop precise timing and coordination of the arm(s) swing during each support phase. Also, the primary contributor to the total vertical force is the rapid extension of the takeoff leg. Therefore, the ability of novice jumpers to accelerate their mass could be improved by increasing the strength and power of the ankle, knee, and hip extensors. Most coaches and jump researchers agree that a training program designed to increase force application should include all of the following training regiments: 1) strength training with weights, 2) power training with weights, 3) depth jumping, and 4) specific power drills such as bounding while wearing a weighted vest. For novice jumpers, however, caution should be exercised in initiating these resistance programs.

Recommendations for Future Studies

Most of the research done on triple jump training and technique was qualitative in nature. In order to enhance the validity of the opinions of these writers, it is important that more quantitative research be done in the area of triple jumping. There are a number of reasons for this country's neglect of quantitative triple jump research. First, the popularity of the long jump in this country has lured most of the horizontal jump researchers into that area. Second, collecting data on large numbers of subjects performing many trials is prohibitive when using 16mm high speed cameras. Setup time can take hours, film is costly, and turnover time is slow. Third, the usual procedure of manually decoding the data is a laborious task. Finally, the difficulty in analyzing the many interrelated variables associated with the multiple support and flight phases deters all but the most dedicated researchers.

Public interest in the triple jump, however, has recently been heightened in light of the gold medal performance of Al Joyner in the 1984 Olympic Games and the recent world record performances of Willie Banks and Mike Conley. Record breaking performances such as these should also entice more track and field researchers into triple jump research.

The problems inherent in collecting and decoding data on multiple takeoff phases, however, will not be easily overcome. Actually, these problems are not unique to triple jump research. They are a stumbling block for anyone interested in obtaining accurate and meaningful data in the least amount of time. Teachers of movement skills, athletic coaches, and biomechanists all face these problems. There is, therefore, a need for future studies with the objective of determining the best way to simplify the task of data collection and decoding so that it can become accessible to everyone. The area of automated video technologies would be an excellent place to start.

The use of appropriate statistical analyses would greatly simplify the task of analyzing the many interrelated variables associated with complex performances such as the triple jump. Statistical procedures, however, work best when used to analyze large numbers of randomly selected subjects performing numerous trials. For the reasons stated in Chapter 1, random selection is an impossibility in most athletic events. Studies involving large numbers of subjects, however, could become a possibility with the introduction of automated data collection and decoding systems.

Possible Future Research in the Triple Jump

Below is a list of areas in triple jump research that need further investigation. These research possibilities are an extension of the insights gained as a result of conducting this study.

1) Future research studies should be conducted which analyze the developmental process involved in learning to triple jump. This can be done by conducting studies which compare children of different age groups on related triple jump skills. Additional studies similar to Milburn's (1979) comparison of less skilled, moderately skilled, and highly skilled triple jumpers would also shed light on the developmental process. The effects of different training methods on different skill levels should also be investigated.

2) Further studies should be performed comparing the three phases of the triple jump on important intervening variables. Appropriate statistical analysis should be used when making the comparisons.

3) A study should be conducted that analyzes the contribution of the momentum of the arm(s) to the total body momentum while using either a single arm swing or a double arm swing.

4) In addition, studies should be conducted that investigate the use of the arms during the flight phase. It would be interesting, for example, to compare different skill levels on the timing of the arm swing from one takeoff to another.

5) Because of the limited amount of training time available to train the jumpers in this study, it was not possible to address the question of how positioning the arms for the double arm swing effected approach velocity. This question should be addressed more fully. Elite triple jumpers could be used for a study such as this.

6) A study should be conducted comparing the arm and a half style to the parallel double arm style and the single arm style.

7) The question of "balance" in triple jumping needs to be investigated to a much greater extent than it has been in the past. First, the term balance is a misnomer. The term balance is usually reserved for static cases in most physics and engineering text books. It would be better to use the engineering term dynamic stability. Second, the concept must be clearly defined. Most coaches describe balance in the frontal plane in terms of how much the midline of the jumper's trunk deviates from some vertical reference line. This definition, however, does not take into account twisting motions in the transverse plane or movements that take place in the sagittal plane. Third, given some agreed upon definition, measurement procedures must be devised. In order to analyze twisting movements as well as movements in the sagittal plane, an appropriate three dimensional measurement system must be used.

8) For years triple jump coaches and researchers have reported phase contributions for many of the great triple jump performances; this was done in this study also. When reporting their findings, however, most writers rarely reported how the phase distances were measured. Did they measure the displacement of the total body center of mass during each flight phase, or as would be the case with most coaches, did they use the takeoff foot as a reference and then measure the distance between each takeoff and subsequent landing? Without this information, there is very little validity in a study that compares its findings for phase contributions to the findings of some other researcher. For this reason, it is important that future triple jump studies identify this information.

9) As discussed in Chapter 1, most coaches who have debated the advantages and disadvantages of the single and double arm styles have been concerned with the jumpers' ability to generate force. They should be made aware, however, that great takeoff force does not necessarily result in great takeoff velocities. Ramey (1970) explained:

> The preceding observations show that there is an intimate relationship between the maximum force exerted at take-off, the impulse, and the initial vertical velocity. It has been shown that different maximum forces can produce the same impulses (due to the different durations of these forces), which can yield different initial velocities (due to different masses). It is of interest to note that, by

themselves, the maximum force and impulse are not the primary variables but their importance appears in the combination of the force-impulse-mass relationship. This relationship shows that it is desirable to have an athlete that can produce a large net vertical impulse in proportion to his weight (p. 150).

10) Further attempts should be made to analyze the force-impulse-mass relationship described above by Ramey through the use of direct measurement techniques. Before this can be done, however, more work is needed to perfect the use of force plates in triple jump research.

APPENDIX A

APPENDIX A

DEFINITION OF INTERVENING VARIABLES

The Frontal View

ATFHTO: Angle of inclination of the trunk in the frontal plane at hop takeoff

ATFSTO: Angle of inclination of the trunk in the frontal plane at step takeoff

ATFJTO: Angle of inclination of the trunk in the frontal plane at jump takeoff

The Sagittal View

FORCEXH: The average horizontal force generated over the entire hop support phase

FORCEYH: The average vertical force generated over the entire hop support phase

FORCEXS: The average horizontal force generated over the entire step support phase

FORCEYS: The average vertical force generated over the entire step support phase

FORCEXJ: The average horizontal force generated over the entire jump support phase

FORCEYJ: The average vertical force generated over the entire jump support phase

PROJAH : The projection angle of the hip joint for the hop

PROJAS : The projection angle of the hip joint for the step

PROJAJ : The jump projection angle of the hip joint for the jump

TIMEH : The duration of the hop support phase

TIMES : The duration of the step support phase

TIMEJ : The duration of the jump support phase

VXHTO : The horizontal velocity for the hip joint at the instant of hop takeoff

VYHTO : The vertical velocity for the hip joint at the instant of hop takeoff

VXSTO : The horizontal velocity for the hip joint at the instant of step takeoff

VYSTO : The vertical velocity for the hip joint at the instant of step takeoff

VXJTO : The horizontal velocity for the hip joint at the instant of jump takeoff

VYJTO : The vertical velocity for the hip joint at the instant of jump takeoff

VXDIFFH: The difference between the horizontal velocities at the instant of touchdown and takeoff for the hop support phase

VYDIFFH: The difference between the vertical velocities at the instant of touchdown and takeoff for the hop support phase

VXDIFFS: The difference between the horizontal velocities at the instant of touchdown and takeoff for the step support phase

VYDIFFS: The difference between the vertical velocities at the instant of touchdown and takeoff for the step support phase

VXDIFFJ: The difference between the horizontal velocities at the instant of touchdown and takeoff for the jump support phase

VYDIFFJ: The difference between the vertical velocities at the instant of touchdown and takeoff for the jump support phase

APPENDIX B

Split Plot Design and Layout

Eight subjects were randomly assigned to two groups: a single arm group and a double arm group. The subjects in the two groups were then matched on their long jump ability.Because one subject in the double arm group dropped out of the study, the experiment was conducted with seven subjects:four subjects in the single arm group and three subjects in the double arm group. Because the long jump ability of the subject who dropped out of the double arm group was close to the average of that group, the missing subjects' technique was used. This entailed averaging each performance parameter for the three remaining subjects to determine each parameter of the missing subject. Only the farthest jump was analyzed for each jumper. Each subject was observed three times: once during the hop support phase, once during the step support phase, and once during the jump support phase. A split plot design was used during the data analysis and the appropriate F-tests was used to test the three hypotheses (see Chapter 1).

SPLIT PLOT LAYOUT

ARM STYLE	PHASES	B1	B2	B3	B4	GROUP MEANS	PHASE MEANS
SA	P1	S1	S2	S3	S4		$\bar{y}.11$
	P2	S1	S2	S3	S4		$\bar{y}.12$
	P3	S1	S2	S3	S4		$\bar{y}.13$
Subject Means		$\bar{y}11$	$\bar{y}12.$	$\bar{y}13.$	$\bar{y}14.$	$\bar{y}.1.$	
DA	P1	S5	S6	S7	S8		$\bar{y}.21$
	P2	S5	S6	S7	S8		$\bar{y}.22$
	P3	S5	S6	S7	S8		$\bar{y}.23$
Subject Means		$\bar{y}21.$	$\bar{y}22.$	$\bar{y}23.$	$\bar{y}24.$	$\bar{y}.2.$	
							$\bar{y}...$

where, $\bar{y}ijk$ such that:
- i = subject index (i =1,2,...,8)
- j = group index (j =1,2)
- k = phase index (k =1,2,3)
- SA = single arm group

DA = double arm group
B = pair (1,2,3,4)
P1 = hop
P2 = step
P3 = jump
s = subject (n =8)

ANOVA SOURCE TABLE

Source	df	Mean Square	F
Between Subjects	7		
Arm Style	1		
Pair	3		
Arm Style X Pair	3		
Within Subjects	16		
Phases	2		
Pair X Phase	6		
Arm Style X Pair X Phase	6		
Total	23		

F-TEST

Arm Style (A) = Fixed
Phases (P) = Fixed
Blocks (B) = Random

1) A vs AxB

$$\frac{MS_A}{MS_{AxB}} = F$$

2) P vs BxP

$$\frac{MS_P}{MS_{BxP}} = F$$

3) AxP vs AxBxP

$$\frac{MS_{AxP}}{MS_{AxBxP}} = F$$

APPENDIX C

APPENDIX C

TIME

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	55.431	6	9.238		
Pair (B)	14.623	3	4.874		
Phase (P)	16.001	2	8.000	2.09	NO
Style (A)	24.807	1	24.807	17.11	.05
2-Way Interaction	69.295	11	6.300		
Pair Phase (BxP)	22.929	6	3.822		
Pair Style (AxB)	4.350	3	1.450		
Phase Style (AxP)	42.016	2	21.008	3.46	.10
3-Way Interaction Pair Phase Style A x B x P	36.387	6	6.065		
Explained	161.113	23	7.005		
Residual	0.000	0	0.000		
Total	161.113	23	7.005		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3} = \frac{24.807}{1.450} = 17.108$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6} = \frac{8.000}{3.822} = 2.093$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6} = \frac{21.008}{6.065} = 3.464$

VX

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	2.117	6	0.353		
Pair (B)	1.794	3	0.598		
Phase (P)	0.313	2	0.157	.987	NO
Style (A)	0.009	1	0.009	.021	NO
2-Way Interaction	2.309	11	0.210		
Pair Phase (BxP)	0.952	6	0.159		
Pair Style (AxB)	1.257	3	0.419		
Phase Style (AxP)	0.101	2	0.051	0.548	NO
3-Way Interaction Pair Phase Style A x B x P	0.556	6	0.093		
Explained	4.982	23	0.217		
Residual	0.000	0	0.000		
Total	4.982	23	0.217		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{0.009}{0.419}$

$= .021$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{0.157}{0.159}$

$= .987$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{0.051}{0.093}$

$= 0.548$

VY

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	4.028	6	0.671		
Pair (B)	0.400	3	0.133		
Phase (P)	3.609	2	1.805	41.02	.001
Style (A)	0.020	1	0.020	1.11	NO
2-Way Interaction	0.513	11	0.047		
Pair Phase (BxP)	0.261	6	0.044		
Pair Style (AxB)	0.053	3	0.018		
Phase Style (AxP)	0.199	2	0.099	1.08	NO
3-Way Interaction	.0552	6	0.092		
Pair Phase Style A x B x P		6			
Explained	5.094	23	0.221		
Residual	0.000	0	0.000		
Total	5.094	23	0.221		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{0.02}{0.018}$

$= 1.11$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{1.805}{0.044}$

$= 41.02$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{0.099}{0.092}$

$= 1.08$

VXDIFF

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1.545	6	0.257		
Pair (B)	1.025	3	0.342		
Phase (P)	0.357	2	0.179	0.840	NO
Style (A)	0.163	1	0.163	1.25	NO
2-Way Interaction	3.388	11	0.308		
Pair Phase (BxP)	1.278	6	0.213		
Pair Style (AxB)	3.390	3	0.130		
Phase Style (AxP)	1.720	2	0.860	3.094	NO
3-Way Interaction	1.667	6	0.278		
Pair Phase Style A x B x P	1.667	6	0.278		
Explained	6.600	23	0.287		
Residual	0.000	0	0.000		
Total	6.600	23	0.287		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{0.163}{0.130}$

$= 1.25$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{0.179}{0.213}$

$= 0.840$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{0.860}{0.278}$

$= 3.094$

VYDIFF

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	1.271	6	0.212		
Pair (B)	0.495	3	0.165		
Phase (P)	0.486	2	0.243	1.52	NO
Style (A)	0.289	1	0.289	5.35	NO
2-Way Interaction	2.039	11	0.185		
Pair Phase (BxP)	0.961	6	0.160		
Pair Style (AxB)	0.162	3	0.054		
Phase Style (AxP)	0.916	2	0.458	2.01	NO
3-Way Interaction Pair Phase Style A x B x P	1.370	6	0.228		
Explained	4.680	23	0.203		
Residual	0.000	0	0.000		
Total	4.680	23	0.203		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{0.289}{0.054}$

$= 5.35$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{0.243}{0.160}$

$= 1.52$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{0.458}{0.228}$

$= 2.01$

PROJ

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	633.068	6	105.511		
Pair (B)	107.969	3	35.990		
Phase (P)	522.723	2	261.362	45.95	.001
Style (A)	2.375	1	2.375	0.370	NO
2-Way Interaction	95.530	11	8.685		
Pair Phase (BxP)	34.128	6	5.688		
Pair Style (AxB)	19.274	3	6.425		
Phase Style (AxP)	42.127	2	21.064	1.65	NO
3-Way Interaction Pair Phase Style A x B x P	76.431	6	12.739		
Explained	805.029	23	35.001		
Residual	0.000	0	0.000		
Total	805.029	23	35.001		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{2.375}{6.425}$

$= .3696$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{261.362}{5.688}$

$= 45.95$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{21.064}{12.739}$

$= 1.65$

TRUNK

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	37.276	6	6.213		
Pair (B)	19.568	3	6.523		
Phase (P)	10.226	2	5.113	0.575	NO
Style (A)	7.482	1	7.482	0.671	NO
2-Way Interaction	93.535	11	8.503		
Pair Phase (BxP)	53.374	6	8.896		
Pair Style (AxB)	33.435	3	11.145		
Phase Style (AxP)	6.726	2	3.363	0.295	NO
3-Way Interaction Pair Phase Style A x B x P	68.408	6	11.401		
Explained	199.218	23	8.662		
Residual	0.000	0	0.000		
Total	199.218	23	8.662		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{7.482}{11.145}$

$= .671$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{5.113}{8.893}$

$= .575$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{3.363}{11.401}$

$= .295$

TOEHIP

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	0.364	6	0.061		
Pair (B)	0.350	3	0.117		
Phase (P)	0.014	2	0.007	0.025	NO
Style (A)	0.001	1	0.001	1.00	NO
2-Way Interaction	1.769	11	0.161		
Pair Phase (BxP)	1.649	6	0.275		
Pair Style (AxB)	0.003	3	0.001		
Phase Style (AxP)	0.117	2	0.058	0.569	NO
3-Way Interaction Pair Phase Style A x B x P	0.615	6	0.102		
Explained	2.748	23	0.119		
Residual	0.000	0	0.000		
Total	2.748	23	0.119		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{.001}{.001}$

$= 1.00$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{.007}{.275}$

$= .025$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{.058}{.102}$

$= .569$

FORCEY

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	89625.695	6	14937.616		
Pair (B)	11642.788	3	3880.929		
Phase (P)	63960.439	2	31980.220	1.50	NO
Style (A)	14022.467	1	14022.467	0.66	NO
2-Way Interaction	174149.860	11	15831.805		
Pair Phase (BxP)	100083.971	6	16680.662		
Pair Style (AxB)	64129.357	3	21376.452		
Phase Style (AxP)	9936.532	2	4968.266	0.31	NO
3-Way Interaction Pair Phase Style A x B x P	94818.261	6	15803.043		
Explained	358593.816	23	15591.035		
Residual	0.000	0	0.000		
Total	358593.816	23	15591.035		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{14022.467}{21376.452}$

$= .66$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{31980.220}{21376.452}$

$= 1.496$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{4968.266}{15803.043}$

$= .314$

FORCEX

Pair
BY Phase
Style

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	76884.558	6	12814.093		
Pair (B)	38741.031	3	12913.677		
Phase (P)	26967.676	2	13483.838	1.17	NO
Style (A)	11175.850	1	11175.850	3.67	NO
2-Way Interaction	187562.273	11	17051.116		
Pair Phase (BxP)	69302.768	6	11550.461		
Pair Style (AxB)	9139.675	3	3046.558		
Phase Style (AxP)	109119.829	2	54559.915	5.86	.05
3-Way Interaction Pair Phase Style A x B x P	55861.571	6	9310.262		
Explained	320308.401	23	13926.452.		
Residual	0.000	0	0.000		
Total	320308.401	23	13926.452		

1) $\frac{MS_A}{MS_{AxB}} = F_{1,3}$

$= \frac{11175.850}{3046.558}$

$= 3.67$

2) $\frac{MS_P}{MS_{BxP}} = F_{2,6}$

$= \frac{13483.838}{11550.461}$

$= 1.17$

3) $\frac{MS_{AxP}}{MS_{AxBxP}} = F_{2,6}$

$= \frac{54559.915}{9310.262}$

$= 5.86$

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