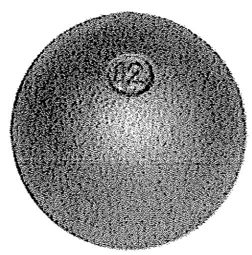
THE UNIVERSITY OF MANITOBA

"A BIOMECHANICAL COMPARISON OF THE ROTATIONAL SHOT PUT TECHNIQUE USED BY MALES AND FEMALES"

By

Carolyn Taylor



A Thesis
Submitted to the Faculty of Graduate Studies
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For the Degree of

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A BIOMECHANICAL COMPARISON OF THE ROTATIONAL SHOT PUT TECHNIQUE USED BY MALES AND FEMALES

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Carolyn Taylor

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

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DEDICATION

I would like to dedicate this thesis to my family whose unconditional love and support gives me the strength to pursue my dreams. Your unwavering confidence in me is the reason why I believe I achieve whatever I set my mind to.

With love,

Carolyn

ABSTRACT

Currently eight out of the top ten ranked male shot putters in the world use the rotational shot put technique and the men's shot put world record was thrown by an athlete using the rotational shot put technique. Currently, the top ranked female shot putters do not use the rotational technique as they continue to use the glide technique at the elite level. The purpose of this study was to examine the rotational shot put technique used by females and males and to determine if there were any biomechanical differences between the genders. Eighteen subjects were filmed for this study – ten male and eight female rotational shot putters from NCAA division II universities and colleges and the University of Alberta. Fifty-one variables were measured using Dartfish TeamPro 4.0.7 software, and Microsoft Excel and StatView 4.0 were used for the statistical analysis. The females showed significantly shorter throw distances than the males by 3.02m ($p \leq 0.001$). Several additional differences between variables measured were found to be significant between the males and females with the main differences occurring in the second turn. In order to determine which variables best determine throw distance, correlation and forward stepwise multiple regression analyses were conducted. Vertical velocity was found to have the strongest relationship to male throw distance ($r=0.602$) but trunk flexion at maximum backswing was found to have the strongest relationship to female throw distance ($r=-0.771$). Stepwise regression analysis of the female group identified 5 variables as the key predictors of throw distance, 3 of which occur during the second turn. Stepwise regression analysis of the male group identified 7 variables which explained over 99% of the variation in throw distances, and 6 of these variables occurred in the second turn.

CHAPTER I
INTRODUCTION

GENERAL OVERVIEW

The world record holder in men's shot put is Randy Barnes from the United States who threw 23.12 in 1990 (*Men's Shot Put, 2006*). Randy Barnes used the rotational shot put technique. The men's 2004 Indoor Champion, 2005 Outdoor Champion and current 2006 Indoor Champion are all use the rotational shot put technique. In contrast, no female rotational shot putter has ever won a World or Olympic Championship. Considering that the males have been very successful with the technique, why the females have not adopted the technique remains an enigma.

One theory attempting to explain the few female rotational shot putters is that the physiological differences, as well as the differences in the weight of the implement between males and females do not make this a good technique for females (Goss-Sampson & Chapman, 1997; Lemke, Hellier, Supko, Murphy, 2003). For example, women may be too flexible and may not be able to get into a tightly coiled position like the men (Lemke et al., 2003) or that the increased flexibility, "leads to extreme wind-up positions which make an effective delivery difficult" (Goss-Sampson & Chapman, 1997, p.22). The fact that the implement thrown by females is 3.26kg lighter leads others to believe the implement provides insufficient resistance and makes a torqued position more difficult to attain, which is supposed to be one of the advantages of the rotational shot put technique (Goss-Sampson & Chapman, 1997; Lemke et al., 2003, p.144). However, neither one of these theories has scientific evidence to support their claims.

For every coach that believes there is a physiological reason why women do not use the rotational technique, there is a coach that believes it has nothing to do with physical gender differences. Perhaps the most widely accepted theory has been that there has yet to be a female rotator successful at the international level and no one to lead the movement (Goss-Sampson & Chapman, 1997;(Lemke, 2003). The head coach for the Queensland Academy of Sport, Steve Lemke, feels that, "as a female breaks through at the international level using the rotational technique, we will see more women employing the rotation at international events. When this happens, there will be a natural trickle-down effect" (Lemke et al., 2003). Just this year, American rotational shot putter Jillian Camarena broke the top ten in the world ranks and is currently ranked 8th in the world while fellow American and rotational shot putter Laura Gerraughty ranked 16th (*Women's Shot Put,* 2006). The next few years could see an evolution of the women's shot put event if Lemke's predictions hold true.

Finally, some coaches feel that there is an absence of coaches willing to teach the technique (Lemke et al., 2003). Some have suggested coaches have too much respect for the linear technique with respect to coaching female shot putters (Goss-Sampson & Chapman, 1997).

The only way to answer the question of the overwhelming successful male rotational shot putters and the lack of successful female rotational shot putters is through more scientific research. Until the shot put world has a clear understanding of biomechanics involved in the female rotational shot put, coaches will be hesitant, females will not be encouraged and the chances of producing a female rotational shot put champion will be minimal.

ORIGINS OF THE SPORT

Early organized forms of the shot put date back to the 17^{th} century when English soldiers organized cannonball throwing competitions. However, there is evidence of rock throwing competitions by soldiers during the siege of Troy according to the writings of Homer (author, 2005). In the early 19^{th} century, Scotsmen, in a test of manhood, would throw large stones to prove their strength and the sport was referred to as "casting of the stone" then later, "putting of the weight" (www.rctsd.ca). The term "weight" is "an old English measure equaling 16 pounds [7.26 kilograms] that is the weight of the modern shot in [men's] track and field" (www.rctsd.ca). In 1860, many of the rules for competition were laid out such as having to hold the shot in the crook of the neck, and having to throw from a square with 7 foot sides – replaced by a seven foot diameter circle in 1906 (author, 2005). As the sport developed and grew in popularity the term "shot put" was then used to describe the sport in the early 20^{th} century. The term "shot" refers to the throwing implement which originates from the old practice of using cannon balls occasionally instead of a stone, and "put" is an old Scottish verb meaning "to thrust" (www.rctsd.ca).

HISTORY OF WOMEN'S SHOT PUT

The first shot put competition with a 4 kilogram shot was held in France in 1917 (author, 2005). During this time, women could also compete in a 5 kilogram shot put event, but this event was dropped in 1927 (author, 2005). The International Olympic Committee (IOC) recognized the first women's shot put world record in 1924 when Violette Gouraud-Morris from France threw the 4kg shot 10.15 meters (www.olympics.org, 2002). Fanny Rosenfeld was Canada's first internationally ranked shot putter when she put the 8 pound ball 11.04 meters in Toronto in 1925 (Olszewski, 2003). Fanny Rosenfeld held the Canadian 4 kilogram record of 10.64 in 1928 until Mamie Schrum surpassed Rosenfeld's throw with a put of 11.35 in 1932 (far behind the top female throw that year of 13.25m) (Olszewski, 2003). In 1948, women's shot put made its Olympic debut (author, 2005; Olszewski, 2003). "The only other major games opportunity for Canadian women of the era, the British Empire/Commonwealth Games, didn't bring the shot into its program until 1954!" (Olszewski, 2003). Unfortunately, no Canadian women entered the 1948 or 1952 Olympic Games, however in 1954, Vancouver held the 5th British Empire and Commonwealth Games and of the four Canadian women that entered the event, Jackie MacDonald took second place with a throw of 12.98m (Olszewski, 2003). By this time, the women's world record was now 16.28 meters and was held by Galina Zybina of the Soviet Union who broke her own record three more times until fellow countrywoman Tamara Press put the shot 17.25 meters in 1960 (www.olympics.org, 2002).

Currently, the Canadian record is 17.17m held by Carmen Ionesco of Quebec and has not been broken in over 27 years, since it was set in 1979 (Olszewski, 2003). Manitoban Melody Torcolacci put the shot 17.21 meters in 1987, however the implement was not officially weighed and therefore is not eligible to stand as the Canadian record (Olszewski, 2003). The last Canadian woman to throw the shot over the 17 meter mark was Albertan Georgette Reed in 1996 with a throw of 17.01 meters (Olszewski, 2003). The current women's shot put world record has not been broken in over 19 years and is held by Natalia Lisovskaya from the former Soviet Union with a throw of 22.63 meters set back in 1987. Individuals involved with the sport speculate that it is stricter enforcement of rules against performance enhancing drugs that has led to the endurance of this record. "The top [shot put] distances for the last decade have decreased, especially for women, perhaps due to increased anti-doping efforts" (www.en.wikipedia.org, 2006). In fact, no woman has been within a meter of the world record since 1990 (www.olympics.org, 2002).

In terms of women and the rotational shot put technique, Bartonietz (2004) acknowledges the accomplishments of Wyludda and Simm – both junior rotational shot putters who in 1983 threw 15.18 meters and 18.41 respectively, with Constanze Simm winning the European Junior Championships. Astrid Kumbernuss from Germany had the potential to be the first female rotational shot putter to make the finals in 1992 as she threw 20.03 meters that year. Unfortunately, Kumbernuss was seriously injured and was unable to compete in the Barcelona Olympics. Instead, the 1997 World Championships in Athens, Greece marked the first time a female rotational shot putter reached the final of a major international competition (Oesterreich, 1999).

THE IMPLEMENT

Today's modern shot is a manufactured ball typically made of solid brass or iron, with the indoor balls commonly made of a shell of metal that is filled with lead or other material (see Fig. 1-1). The IAAF regulates the material, size and weight of the shots used for various competitions. This information is included in rule 188 of the IAAF

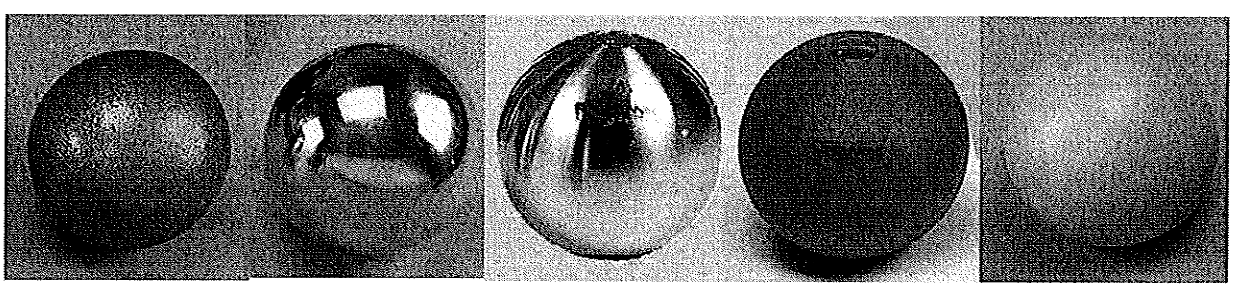


Fig. 1-1: Various types of shot puts used in today's competitions. From left to right: cast iron shot, solid brass shot, stainless steel shot, solid steel shot and polyvinyl plastic shot.

2006-2007 Competition Rules book (see Fig.1-2). The weight of the shot varies with the gender and age of the athlete. Women use a 4 kilogram shot from youth to senior levels while youth boys begin with a 5 kilogram shot, move up to a 6 kilogram shot in the junior ranks then are required to throw a 7.26 kilogram shot at the senior level (IAAF, 2005).

SHOT				
Minimum weight for admission to competition and acceptance of a record:				
	Females	*Youth males*	*Junior males*	*Senior males*
	4.000kg	5.000kg	6.000kg	7.260kg
Allowable range for supply of implement for competition:				
	4.005kg	5.005kg	6.005kg	7.265kg
	4.025kg	5.025kg	6.025kg	7.285kg
Minimum Diameter:	95mm	100mm	105mm	110mm
Maximum Diameter:	110mm	120mm	125mm	130mm

Fig. 1-2: Official shot put size and weight regulations as stated by the IAAF.

THE RULES

In shot putting, athletes try to project a shot as far as possible while remaining within the confines of the throwing circle (Linthorne, 2001). In competition, if the thrower touches the outside of the circle or the top of the toe board before the throw has landed, then a foul is called and the throw does not count. Moreover, the shot must land

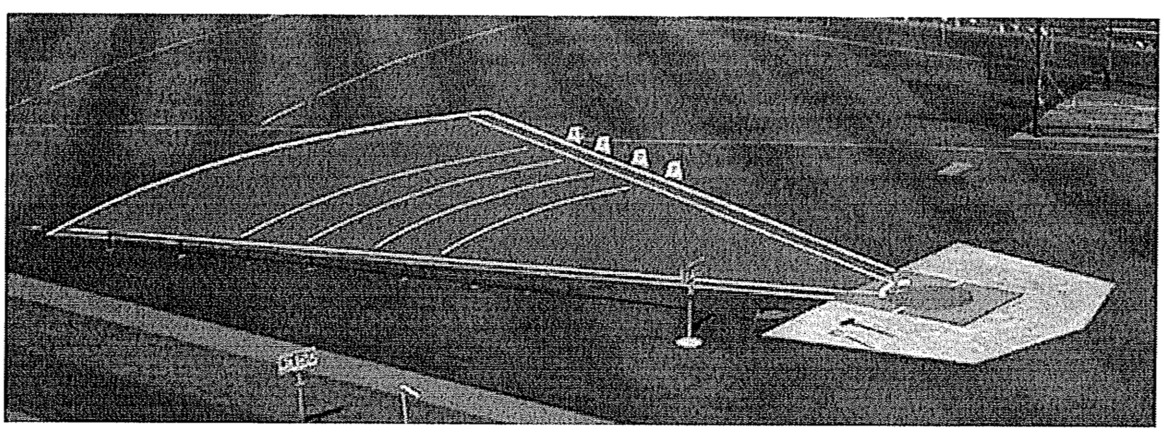


Fig. 1-3: Shot put circle and landing sector.

within the marked landing sector (Fig. 1-3). If the throw falls outside of these lines, then the throw is ruled a foul. The athlete must be very strong, explosive, quick and agile and must remain in balance and control in order to execute a long throw and have it count. Following the landing of the shot, the athlete must exit through the back half of the shot circle. In the event the athlete leaves the front of the circle, or leaves the circle before the shot has landed, the throw will be ruled a foul.

THE CIRCLE

In addition to the shot, the IAAF also regulates the dimensions of the throwing circle and sector. The interior of the throwing circle (which was originally a square) measures 2.135m in diameter and can be made out of either concrete, synthetic, asphalt, wood or any other material that is firm but not slippery (IAAF, 2005). Furthermore, the surface of the circle must sit 1.4-2.6cm lower than the upper edge of the rim of the circle (IAAF, 2005). Another prominent feature of the circle is a 10 cm high toe board in the front of the circle that is firmly fixed to the ground and can vary from 11cm to 30cm in

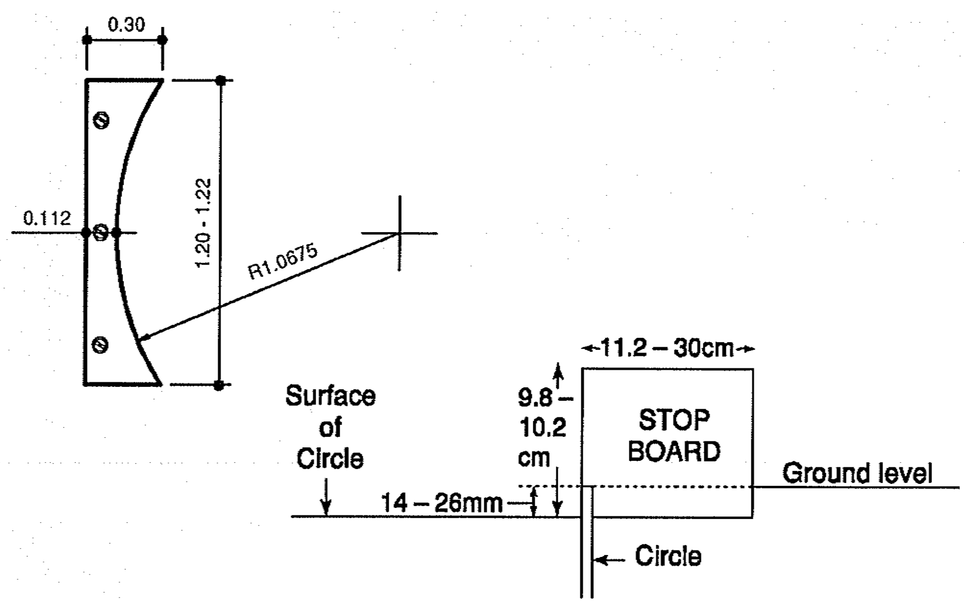


Fig. 1-4: Dimensions of the stop board that is oriented at the front of the shot put circle.(IAAF, 2005).

width. The stop board extends 1.2m along the front arc of the circle (see Fig.1-4). Drawn on the platform surrounding the circle, a 5cm white line extends to a minimum of 75cm from the rim of the circle on either side and these lines are oriented at 90-degrees to the midline (centre line) of the landing sector (IAAF, 2005). Rule 187 of the IAAF rulebook states that the landing sector (the area in which the shot must land) must be of a material that allows the implement to make an imprint and must not exceed a downward inclination of 1:1000 (IAAF, 2005). The sector must be outlined with white lines 5cm thick and angled 17.46-degrees from the centre line of the sector starting from the centre of the circle, but not marked until the outside edge of the toe board (IAAF, 2005) (see Fig.1-5).

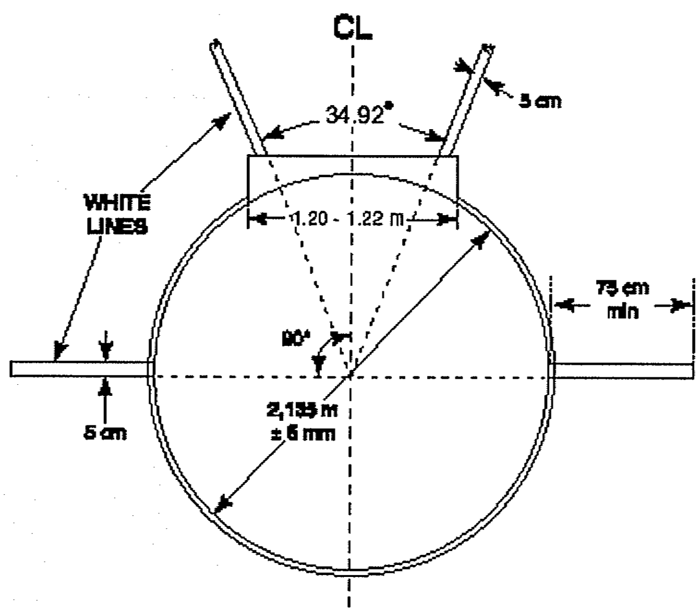


Fig. 1-5: Overhead view of the shot put circle and the dimensions of the throwing sector (IAAF, 2005).

THE STYLES

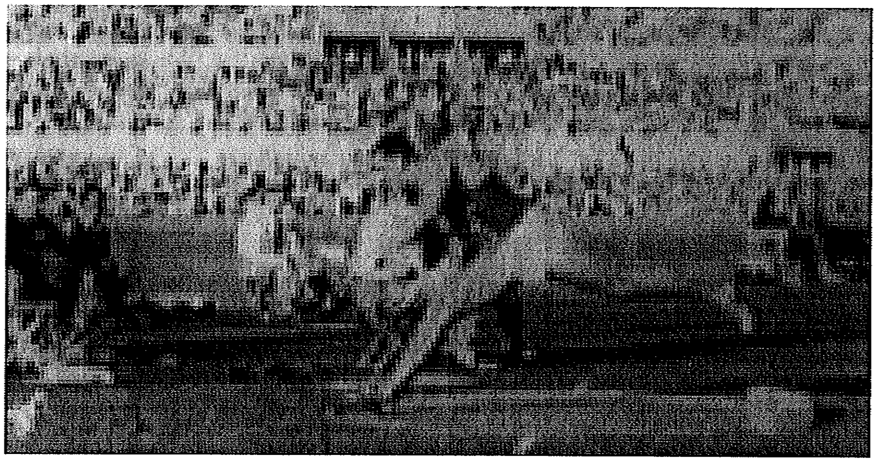


Fig. 1-6: Picture of Parry O'Brien competing in a shot put competition in the 1960's using the glide technique (www.macthrowvideo.com/photos, 2006)

There have been several different styles used in competitions throughout the years however, there are two predominant techniques used today, the glide technique and the rotational technique. No matter which technique is used "shot-putting requires great explosive strength, together with the ability to perform precisely timed movements in a confined space" (IAAF, 2005). In fact, the delivery phase of the shot is similar in both techniques (IAAF, 2005), however, the technique by which each style of shot putter arrives at this final power position varies significantly.

Glide Technique: (described for right-handed thrower)

The glide technique was invented by American shot putter Parry O'Brien in 1951 and is commonly referred to as the "O'Brien" technique. The glide technique begins with the shot putter facing the back of the circle, 180-degrees away from the intended direction of the throw (www.en.wikipedia.org, 2006) (See Fig. 1-6). The shot putter then places all of his/her weight on the right leg as the left leg is kept behind the body and used to keep the athlete balanced. Once the athlete is balanced, the athlete flexes the left hip forward to get any additional loading of the right leg (in order to initiate the stretch-reflex within the quadriceps of the right leg), then explosively extends both the right knee and hip while simultaneously extending the left hip and driving the body backward to the middle of the circle. The athlete tries to keep the centre of gravity within the body and moving in a horizontal plane so that the athlete lands in the middle of the circle with the right knee and hip in a flexed position. After the right foot touches down, the athlete plants the left foot in the front of the shot put circle as close to the stop board as possible. Now the athlete is in the "power position" (see Fig. 1-7) and explosively extends the trunk and both knees and hips, then successively rotates the hips, trunk, and shoulders forward to face the direction of the throw. Following the extension of the lower limbs and rotation of the upper body, the athlete horizontally flexes the shoulder, extends the elbow of the throwing arm, then flexes the wrist and pronates the forearm to release the shot. From an overhead view, the path of the athlete's centre of gravity should remain in a straight line from the middle of the back of the circle to the middle of the front of the circle, whereas the path of the centre of gravity of the shot deviates to the athlete's right as the trunk rotates in the middle of the circle (Fig.1-8)

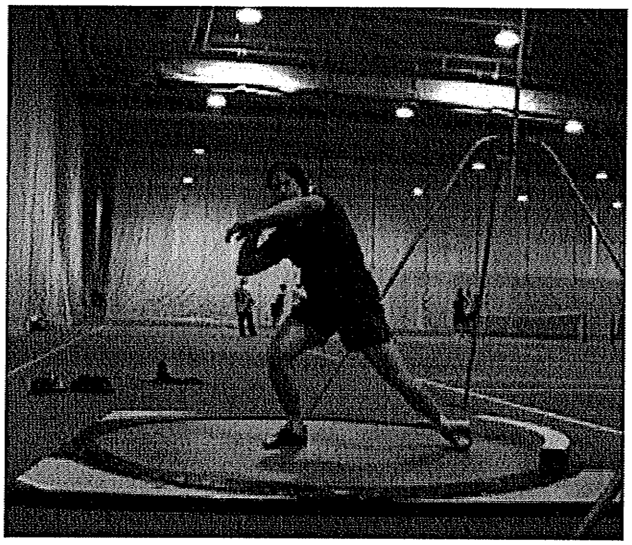


Fig. 1-7: Example of the "power position" of a female shot putter using the glide technique.

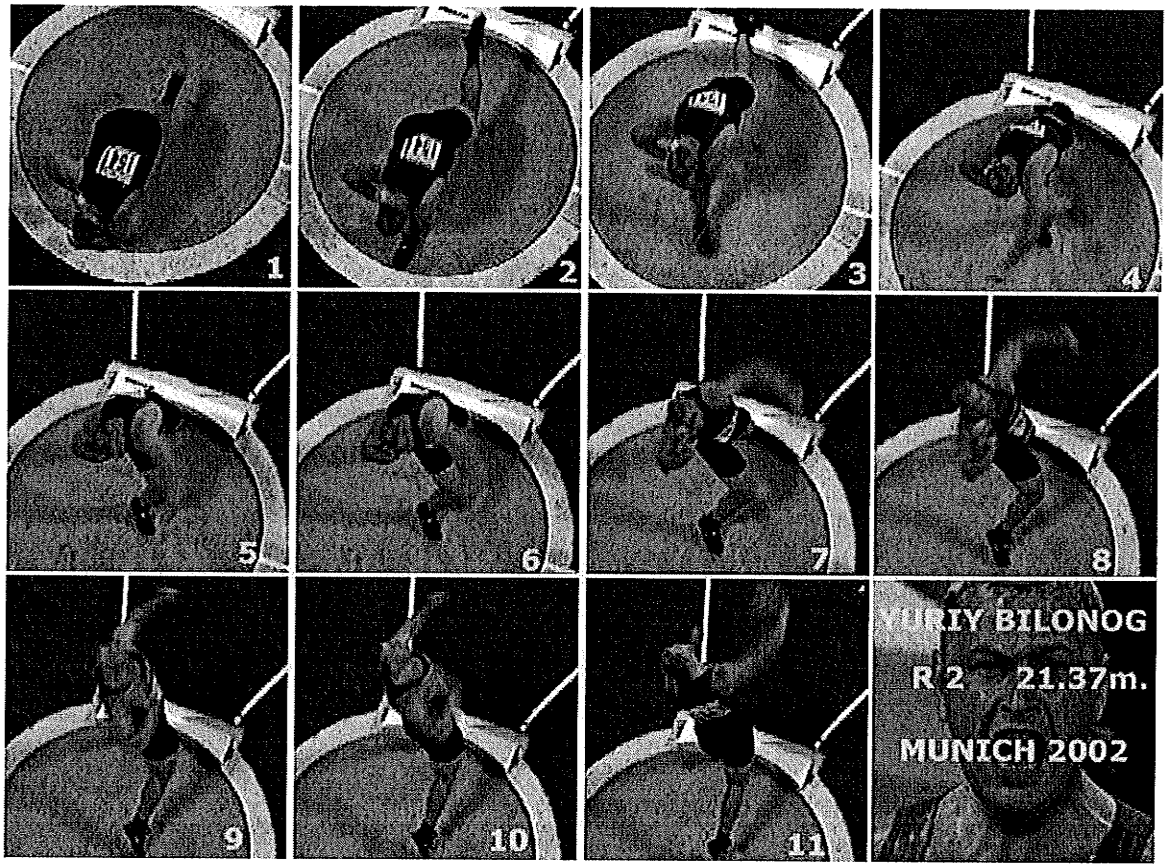


Fig. 1-8: Overhead view of the path of Yuriy Bilonog as he performs the shot put glide technique (www.irishthrowersclub.com).

Rotational Technique: (described for a right-handed thrower)

The rotational technique, first used by O. Chandler in the 1940's, begins with the athlete's toes touching the rim at the back of the circle, as opposed to the one foot position in the glide (Bartonietz, 1994). From this position, the athlete's backswing is a rotation of the shoulder girdle, trunk and hips to the right side with the shot in contrast to flexing the knee of the support leg and flexion of the trunk that serves as the backswing for the glide technique. Following the backswing, the athlete pivots on the left foot and turns towards the middle of the circle, then pushes off. After a brief airborne phase, the athlete should land just past the midline of the circle on the right foot and continue to rotate the lower body quickly while attempting to keep the upper body facing the back of the circle. The trunk and knees remain flexed as the left leg is brought around and planted at the front of the circle. Once both feet are in contact with the ground, the athlete is said to be in the "power position" which is very similar to the power position achieved using the glide technique with the exception of the position of the upper body that tends to be in a more backward rotated position when using the rotational technique (Hall, 2003). From the power position, the rotation of the upper body accelerates as the hips stop rotating and some of the angular momentum from the hip rotation is transferred to the upper body. At the same time, the knees, hips and trunk extend followed by the final force producing movements of elbow extension and wrist flexion.

A CHANGING SPORT

The rotational shot put first gained recognition in 1972 when the pioneer of the technique - Russian shot putter, Aleksandr Baryshnikov, threw 20.54 meters ranking him 12th in the world at the time (Johnson, 1992). However, it was not until American shot putter, Brian Oldfield, threw 21.92 meters at the U.S. Olympic Trials using the rotational style (referred to as the "Baryshnikov style" at the time) that the style gained some credibility – especially after Oldfield switched and threw the shot using the glide technique at the Olympics and only threw 20.91meters (Johnson, 1992). However, as Johnson (1992) points out, the rotational shot put technique has not had a revolutionizing effect on shot putting the same way that the Fosbury flop style changed high jumping. Ten years after the introduction of the Fosbury flop, over 80% of high jumpers had converted to the flop technique (Johnson, 1992), however by 1992, the number of shot putters using the rotational technique was estimated to be around 30% (Johnson, 1992).

Although there have been more 22 meter throws in the last ten years by male rotational shot putters, the glide technique has produced more World and Olympic Medals in the history of the event (Smith, 2005). Currently, the top five shot putters in the world, and 8 of the top ten (as ranked by the IAAF in October 2006) use the rotational technique. The United States, which has embraced the rotational technique, has 12 male shot putters in the top 50 in the sport (24% of the top male shot putters in the world).

In the last decade, athletes using the rotational shot put technique have improved at a greater pace than those athletes still using the traditional glide technique. For example, Arsi Harju from Finland won the 1996 Olympic Gold Medal in shot put and he was a glider up until the autumn of 1995 when he decided to change his technique. Subsequently, there has been an increase in research on the rotational technique, and studies have supported the conclusion that the rotational technique is superior to the glide, "the potential for greater distance is obvious" (Pagel, Pagel, & Silvester, 2003).

A NEED FOR RESEARCH

In recent years there has been an increase in articles analyzing rotational shot put technique as more and more male athletes are having success with it. However, the majority of the literature has focused on the men's technique and the number of studies that have attempted to analyze the technique from a biomechanical point of view, using the concepts of kinematics is limited. Of these more scientifically based analyses, very few have analyzed women with the exception of a group of sport scientists in China (J. Liu, 1996; M. Liu, Sun, T., Xie, K., Ma, Y., 2000) and Young and Li (2005). Due to the limited research on the female rotational shot put technique, more research is required if females are to perfect this technique and maximize the added potential that this shot put style has to offer.

Coaching women's shot put with the male technique model in mind is not good practice, nor helpful to women in the sport considering the magnitude of the gender differences involved. "Males are, on average, 10 cm taller and 19 kilograms heavier than the average female; males are 30 percent stronger in the lower body and up to 50 percent stronger in the upper body than females; males have faster movement time and reaction time; males have only one-third to one-half of the percent of body fat of females; males have wider shoulders and a higher center of gravity than females" (Alexander, 2001). Considering the differences in contribution of the upper and lower body, and analyzing how each contribute to generating force that eventually transfers to the shot, there is reason to believe that the rotational shot put technique used by elite females will differ somewhat from the rotational shot put technique used by their male counterparts. Furthermore, women currently use a shot weighing 4 kilograms which is approximately one half of the weight of the shot men use (7.26 kilograms) and therefore the mass of the women's shot is considerably less. This will have an impact on several kinematic variables such as inertia of the shot, moment of inertia of the upper body about the vertical axis and angular impulse applied by the athlete. However, using the available research and data on the male rotational shot put technique will provide an adequate foundation for comparisons to be made between the genders.

PURPOSE OF THE STUDY

The primary purpose of this study is to determine the biomechanical differences between the rotational shot put technique used by skilled male and skilled female athletes. A sub-purpose of the study is to provide a detailed kinematic analysis of the women's rotational shot put technique that will provide a foundation for further research on female technique.

HYPOTHESIS

1. Male rotational shot putters will have greater flexion angles, larger step lengths and higher velocities (linear and angular) throughout the skill than their female counterparts.

RATIONALE FOR THE STUDY

Superior technique

The rotational shot put technique is superior to the glide technique for several reasons. One of the advantages that has been supported by most shot put and biomechanics experts is the difference in the final power position. Although the final power position is similar in both techniques, the final base of support when using the rotational shot put technique is much narrower than when using the glide technique (Bartonietz, 1994; Lemke, 2003). The decrease in the width of the power position, when compared to the linear technique, allows for the thrower's hips to be closer to the toe board which results in an increased reach over the circle rim and increases the horizontal release distance (Lemke, 2003). In addition, the narrower base of support at release allows the athlete to release the shot at a greater release height. The combination of the more advantageous height of release and horizontal release distance increases the overall potential distance of the throw.

Another advantage of the final power position achieved when using the rotational shot put technique is that the athlete is able to get into a more coiled position. In other words, the rotational shot put technique allows the shot putter to reach a greater shoulder-hip separation in the final power position. "The results of Soviet research, reported by Zatsiorsky tend to support this conclusion. These results showed that, at the beginning of the delivery phase, the difference between the line of the shoulders and the line of the hips (as viewed from a position looking down the long axis of the trunk) may be up to 68-degrees when the rotational technique is used, and only up to 49-degrees when the O'Brien technique is used" (Hay, 1993).

The main advantage to having a greater shoulder-hip separation is that it allows the necessary trunk muscles that will be used to forcefully rotate the trunk to be on a greater stretch and thus, produce more force when the time comes. As such, "the ability to increase velocity during the power position phase is much greater with the rotational [technique]. Rotators are also able to get much more lift from their legs on delivery . . ." (Lemke, 2003).

Aside from the more advantageous power position achieved when using the rotational technique, another advantage of this technique is the training benefits. "In training situations, a thrower is able to perform more repetitions using the rotational technique. The glide technique is very stressful on the lower body in regard to the physical nature of the block (the abrupt stop of the hip rotation). Furthermore, the glide has a more static starting position which requires a greater energy expenditure to initiate movement of the shot (Lemke, 2003). Not only does the rotational technique allow an athlete to practice more during a training session, but, because the rotational shot put technique is easier on the athlete's body, the technique may decrease the number of training sessions lost due to injury. In turn, an athlete can practice more leading up to a competition and still conserve enough energy for the competition.

The rotational shot put technique has also opened the door for more athletes to compete in this field event. The glide technique heavily favors the larger throwers who have much longer levers that allow for a greater height of release and who can move the shot through a greater range of motion during which force can be applied to the shot. Consequently, a shot putter had to be tall and very strong in order to be competitive in the shot put. However, the rotational shot put technique has helped smaller athletes be able to compete with the larger athletes as smaller throwers can compensate for the lack of long levers with superior speed generated by the spinning motion (Steybe, www.steybe.freeservers.com). Furthermore, "massive power outputs can be achieved with slightly lesser levels of maximum strength, possibly allowing spinners to get to world-class levels before gliders" (Lemke, 2003). Thus, as a result of the rotational shot put technique, athletes no longer have to be as tall or as strong in order to be competitive in the shot put (Lemke, 2003). In fact, some of the best known shot putters using the rotational technique such as Oldfield, Godina, Halvari, Barnes and Spiritoso have a substantially lower body mass" (Coh, 2005).

The rotational shot put technique is superior to the glide technique as it has allowed the "little guys" to compete with much larger throwers who use the glide technique. Look no further than the 2004 Olympic Summer Games that took place in Athens Greece for a perfect example. Rotational shot putter Adam Nelson of the United States and Yuriy Bilonog of the Ukraine, who use the glide technique, both threw the shot a measured distance of 21.16m in the 2004 Olympic shot put final. Bilonog won the gold medal as he had fewer faults than Nelson. Yuriy Bilonog is a towering 2m tall individual whose mass is 130kg (www.en.wikipedia.org, 2006) compared to the 1.83m Adam Nelson who has a mass of 102.06kg (www.usatrackandfield.com, 2006). The bronze medalist in the event was Danish shot putter Joachim Olsen who is also a spinner and is 1.84m tall with a mass of 119kg (www.en.wikipedia.org, 2006).

Ariel et al. (2004) collected data at this event and calculated the release angle of both Bilonog and Nelson to be the same at 33 degrees (Olsens was 41 degrees), but Nelson recorded the highest release velocity at 13.95m/s, 0.10m/s faster than Bilonog's release velocity of 13.85m/s. Bilonog, on the other hand, had a release height 0.22m higher than Nelson's 2.33m release height. Eliminating the extra height from which Bilonog was able to release the shot as a result of his taller standing height, 78.4% of Bilonog's release height can be explained by his standing height compared to 78.5% for Nelson's. Thus, the main reason why Bilonog was able to throw the shot as far as Nelson (who had a faster release velocity) on that particular day was due to the fact that Bilonog already had a 0.17m advantage in height. Nelson was the heavy favorite to win the 2004 Olympic gold medal.

When comparing Nelson's personal best to Bilonog's recorded personal best, Nelson surpasses Bilonog by 0.70m (22.51m and 21.81m respectively). Furthermore, the longest personal best throw for the highest ranked male glide shot putter at the beginning of the 2006 season is Ralph Bartels' 21.36m from the Netherlands (the top four shot putters all use the rotational shot put technique). It is also important to point out that Cantwell from the United States is a 6.5" rotational shot putter whose personal best is 22.54m (www.usatrackandfield.com, 2006).

Technique adopted by men but not women

The top female shot putters in the world currently use the glide technique, in fact the top female using the rotational shot put technique in 2006 is Chiara Rosa from Italy who was ranked 22nd in the world at the beginning of the 2006 season. In contrast, eight of the top ten male shot putters in 2005 use the rotational technique and, when looking at the future of the sport, several of the top junior male and female shot putters in the world are using the rotational technique. Since the pioneer of the rotational shot put technique, Aleksandr Baryshnikov, set the world record using the rotational technique back in 1976 (www.olympics.org, 2002), the rotational technique has produced a lot of proponents in male shot putting circles – this has not been the case on the women's side. One possible reason for this is that generally women have yet to master the intricate movements and timing of the rotational technique and consequently, there has yet to be a successful female rotational shot putter. As a result, the technique has not been adopted by many female shot putters. Aleksandr Baryshnikov was also a discus thrower and was experimenting with a new rotational style technique in the discus event, however he was determined that the technique could be beneficial to his shot put. He continued to use the technique for years before setting the world record in 1976. Only in the last year have female rotational shot putters broken the top ten in the world rankings. It is unclear if this recent success will have a similar impact on the female shot put event as Baryshnikov's success had on the male event.

<u>Gender comparison necessary</u>

With the exception of an American rotational shot putter who has recently reached the top eight in the world, no female using the rotational shot put technique has had a great deal of success at the international level. As a result there is no ideal model for women to be compared to. Thus, women's technique must be compared to those of men. "The findings of research conducted on men may not be applicable to women" considering the differences in the equipment and anthropometry (Young & Li, 2005, p.143). Despite few women at the elite international level using the rotational shot put technique, there are a number of younger developing female shot putters using the rotational technique. The United States is the world leader in teaching the rotational technique and has many of their junior ranked shot putters, males and females using the rotational style (Enriquez, 2002). Comparing the technique of the top ranked male shot putters of the world to these junior female rotational shot putters is not a fair comparison. However, comparing these women to the male rotational shot putters that are at a similar learning and developmental level is a much more valid comparison.

Simply analyzing the technique of female rotational shot putters compared to each other will not clearly determine why the males succeed at elite levels with the rotational technique and women currently do not. For this reason, analyzing any technique differences between the sexes at a similar level of rotational shot put skill development will have a better chance of answering this question. The comparison of the rotational shot put technique of females to the rotational shot put technique of their male counterparts is an important question. Any significant differences discovered between the rotational technique used by males and females will determine whether or not the ideal rotational shot put technique for women differ from the technique currently used by men as a result of the differences in body build and strength.

An additional reason for the gender comparison is that there is not enough literature describing the technique of those females who have reached a certain level of success with the rotational shot put technique aside from Young and Li (2005). There has been no model for what the ideal female rotational shot put technique should look like and in order to begin building a model for women, analyzing the aspects of the male rotational shot put technique that has led to men having success using this style of shot put is necessary.

LIMITATIONS

1. Selection of the skilled female and male rotational shot putters was limited primarily to University athletes during practice. This will decrease the generalizability of the results.

2. There are very few skilled female rotational shot putters currently in the world and not all the female rotational shot putters approached for the study wanted to participate; consequently, the sample size was small which may also decrease the generalizability of the results and power of the data.

3. Due to limited availability of the athletes to be filmed, the throws were performed during the training session as filming was not permitted during competition. Therefore, the throws analyzed were not necessarily the athletes' personal best throws.

4. The videos from the digital cameras were synchronized using Dartfish's "timeline" which is limited to 60 fields per second based on the 30 frames per second that is captured by the digital cameras. Thus, the camera views were synchronized to within 1/60 of a second.

5. The legs of the overhead camera apparatus did not extend high enough for the camera to capture a transverse view of all phases of the skill. As a result, the backswing, first double-support and first single-support phase were not captured with the overhead camera.

DELIMITATIONS

1. World ranked males and females were not used for analysis as there are not enough world ranked females skilled in the technique. In order to limit any differences between genders that would result from comparing younger, less experienced female rotational shot putters to elite, world class male shot putters, all of the subjects were at a similar developmental level when compared using the rotational shot put technique. Three of the female subjects are in the top 30 in the world and all of the university athletes qualified for their respective national championships.

DEFINITION OF TERMS

Angle of release: relative angle formed between the path of the shot at release and the horizontal (Young, 2004).

Angular acceleration (α): rate of change in angular velocity with respect to time (Hall, 2003). $\alpha = (\omega_f - \omega_i)/\Delta t$: where α = the average angular velocity; ω_f = the final angular velocity, ω_i = the initial angular velocity and Δt = change in time. In the rotational shot put, athletes wish to maximize angular acceleration of the body during the turns through the circle.

Angular displacement (θ): change in angular position (Hall, 2003). The angular displacement of the line of the shoulder girdle and the shot from the beginning of the second turn to the final release of the shot is typically much greater for those athletes using the rotational shot put technique as opposed to the glide technique.

Angular impulse: product of torque and the time interval over which the torque acts. An angular impulse results in a change of angular momentum (Hall, 2003). Angular Impulse= Tt: where T = torque and t = time.

Angular Momentum (H): quantity of angular motion that is possessed by a body and is measured as the product of moment of inertia and angular velocity (Hall, 2003). $H=mk^2\omega$: where H = angular momentum, m = mass, k = the radius of gyration, ω= the angular velocity.

Angular velocity (ω): the rate of change in the angular position (Hall, 2003). $\omega = \theta/t$: where ω = the angular velocity, θ = angular displacement. In terms of the rotational shot put technique, a greater angular velocity will lead to a greater linear velocity of the shot using the equation $V = r\,\omega$, where V = the linear velocity of the shot, r = the radius (in this case the measurement from the axis of rotation to the shot), and ω = angular velocity of the shot just prior to release.

Average velocity: a vector quantity obtained by dividing the displacement of an object by the time taken for the displacement to occur (Hay, 1993). $v = d/t$: where v = average velocity, d = displacement and t = time.

Axis of rotation: imaginary line passing through the centre of rotation and perpendicular to the plane of rotation (Hall, 2003). The athlete rotates around a vertical axis through the body during the turns in the rotational shot put.

Balance: a state of equilibrium or the ability to control equilibrium (Hall, 2003). Balance is very important to any skill, but in the rotational shot put, poor balance can lead to other major errors in technique and a poor throw.

Base of support (BOS): area bound by the outermost edges of contact between the support surface and a body including the area between contact points if more than one is present (Hall, 2003). In the rotational shot put technique, the base of support during the backswing and double-support phase is the area bound by the outside of the athlete's shoes and the area between the feet. The base of support during the single-support phase is much smaller as it is only the area under the sole of the shoe that is in contact with the surface of the shot circle.

Centre of gravity: point around which an object's mass is equally balanced in all planes (Hall, 2003).

Force (F): produces or prevents motion; the product of mass and acceleration (Hall, 2003). $F = ma$: where F = force, m = mass, a = acceleration. The shot putter applies force to the shot by powerfully contracting key muscles in a sequential order from largest to smallest.

Height of release: perpendicular distance measured from the horizontal plane of the surface inside of the shot put circle to the center of mass of the shot at release (Fig. 1-9).

Fig. 1-9: The height of release is measured from the surface of the circle to the centre of gravity of the shot. The release angle is drawn from the centre of gravity of the shot at release to the centre of gravity of the shot the next frame after release.

Horizontal Release Distance: the horizontal distance measured from the centre of mass of the shot at release and the inside edge of the toe board. This distance is positive when the athlete releases the shot in front of the inside edge of the toe board, and negative when the shot is released from behind the toe board (Linthorne, 2001).

Horizontal velocity (V_H): change in horizontal displacement with respect to time; or velocity in the horizontal direction (Hall, 2003). The release velocity of the shot put can be resolved into its horizontal and vertical velocity components. The horizontal component is the velocity that is multiplied by the total time the shot is in the air to determine the horizontal displacement the shot travels. The vertical component determines the time in the air of the shot (Hay, 1993).

Impulse: the product of the mass and acceleration of a body multiplied by the time over which the acceleration is applied (Hall, 2003). Impulse = Ft: where I = impulse, F = force and t = time.

Impulse momentum relationship: Given the relationship of angular impulse and angular momentum, $Tt=Iw_f - Iw_i$ where T=torque, t=time, I=moment of inertia, w_f=final angular velocity, w_i =initial angular velocity, increasing torque increases the angular impulse that results in an increase in angular momentum in the direction the torque was being applied (Newton's second angular law).

Inertia (I): tendency of a body to resist linear acceleration and preserve its current state of motion (Hall, 2003). The amount of inertia a body/object possesses is directly proportional to its mass – inertia has no units.

Line of gravity: shortest line from the center of gravity of a body to the center of the earth's surface.

Linear displacement (d): vector quantity representing the change in location or the linear distance from initial to final location (Hall, 2003). A shot putter wants to maximize the linear displacement of the shot. Angular displacement of the shot can be converted to linear displacement, when it is multiplied by the radius

($d=r\theta$). Where: d = linear displacement; r = radius; θ = angular displacement (Hall, 2003). Therefore, a shot putter can increase the linear range of motion of the shot by increasing the angular range of motion of the shot.

Linear Momentum (M): quantity of motion that an object possesses measured as the product of mass and linear velocity of that particular object (Hall, 2003). $M = mv$: where M = momentum, m = mass and v = linear velocity.

Moment arm ($d\perp$): perpendicular distance from an axis of rotation to a force's line of action (Hall, 2003).

Moment of inertia (I): inertial property for rotating bodies representing resistance of the body to a change in angular velocity (Hall, 2003). Moment of inertia is equal to the mass times the radius of gyration squared ($I=mk^2$: I= moment of inertia, m=mass, k=radius of gyration – the length of the lever).

Newton's second law of angular motion: "The rate of change of angular momentum of a body is proportional to the torque causing it and the change takes place in the direction in which the torque acts" (Hall, 2003).

Projectile: an object in motion that is subject only to the forces of gravity and air resistance (Hall, 2003). Once the shot has been released by the athlete, the shot is considered a projectile and will follow a parabolic pathway in its flight.

Radius of gyration: the distance the mass of an object is distributed relative to the axis of rotation (Hay, 1993).

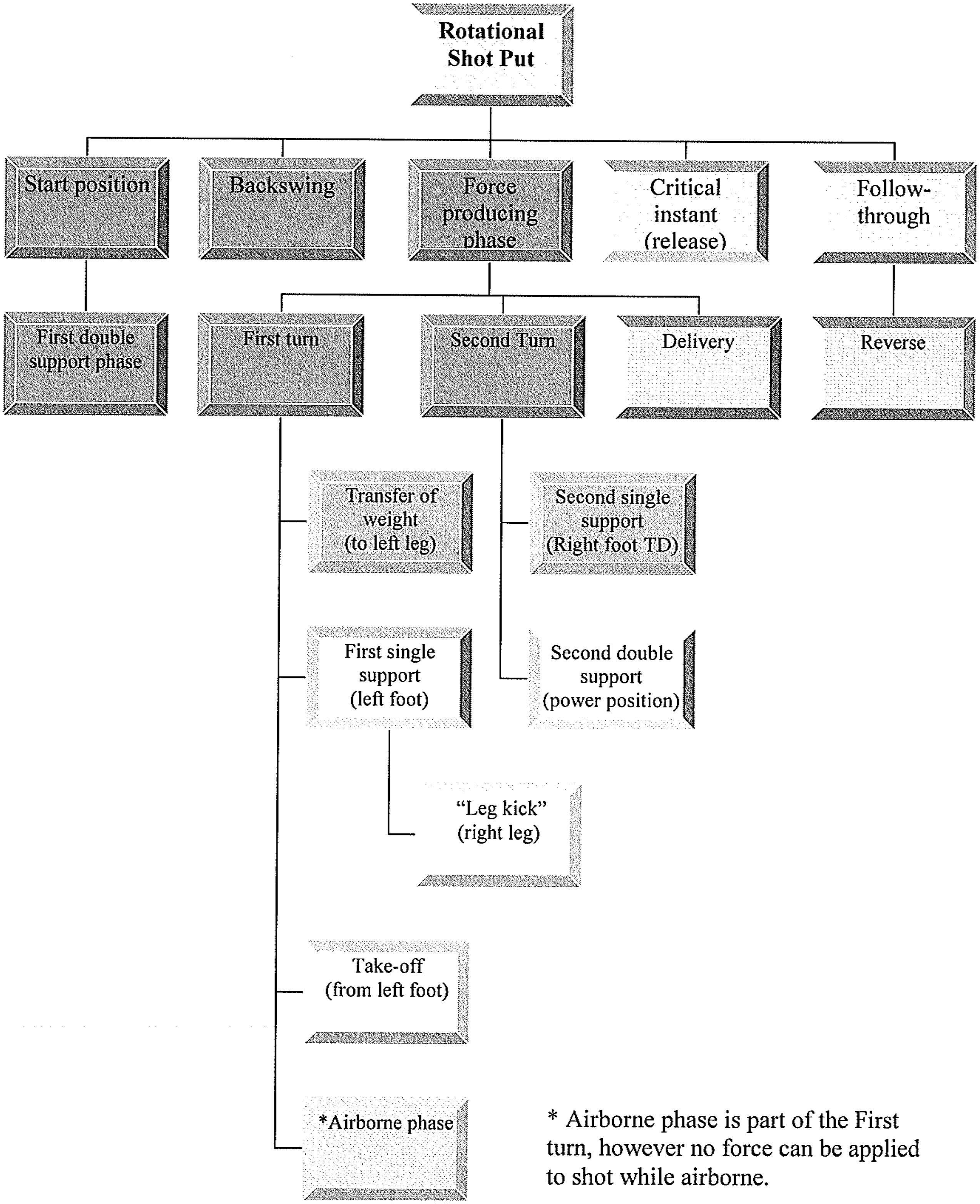
Segmental rotation: when individual segments rotate in a sequential order (usually from largest joint to smallest) as opposed to all joints rotating at once (block rotation) (Alexander, 2002). During the force producing phase of the shot put skill (glide or rotational) the athlete rotates the hips, trunk and then shoulders followed by the extension of the elbow and finally the flexion of the wrist. Novice shot putters will rotate their hips and shoulders together rather than each segment separately.

Throw distance: shortest measured distance from the inside circumference of the shot put circle to the nearest mark made by the fall of the shot (Linthorne, 2001).

Torque (T): the rotary effect of a force about an axis of rotation that is measured as the product of the force and the perpendicular distance between the line of action of the applied force and the axis of rotation (Hall, 2003). $T = Fd_{\perp}$: where T = torque, F = force and $d_{\perp}$ = moment arm.

Vertical velocity (V_V): change in vertical displacement with respect to time (Hay, 2003). Every shot putter releases the shot at some angle to the ground. This velocity of the shot at release is thus directed at an angle to ground. When determining the distance the shot will travel, the release velocity is broken down into its horizontal and vertical velocity components. The vertical component of velocity is used to determine the time the shot is in the air before landing on the ground.

PHASES OF THE ROTATIONAL SHOT PUT OUTLINED
(right-handed putter)



* Airborne phase is part of the First turn, however no force can be applied to shot while airborne.

PHASES OF THE ROTATIONAL SHOT PUT EXPLAINED
(All definitions refer to a right-handed putter in the order that the movements occur during the skill)

Start position: the initial position maintained by the athlete, prior to any movement (backswing or force-producing).

- The athlete assumes a position standing at the back of the circle facing the back-right quadrant prior to the throw. Some athletes assume more of a squat position (Fig. 1-10).

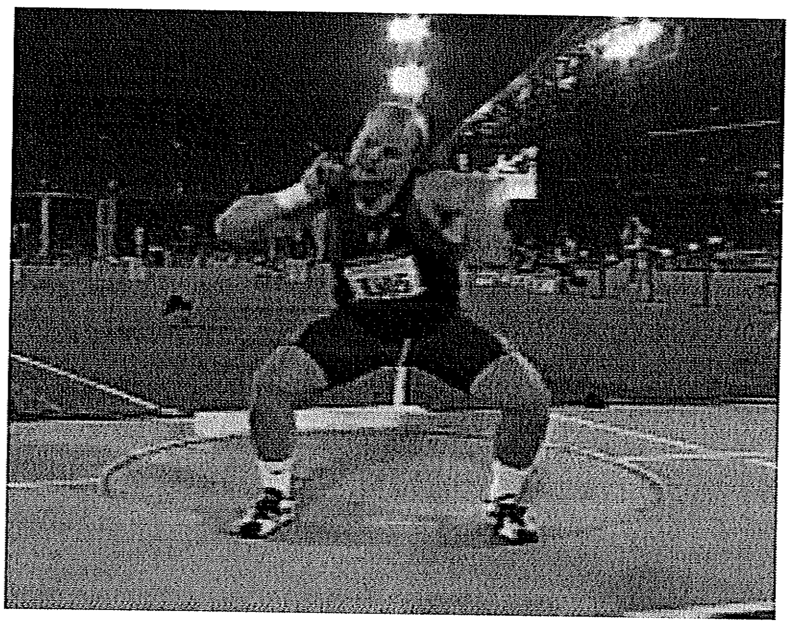


Fig. 1-10: Example of Adam Nelson's starting position at the 2000 Olympic Summer Games in Sydney Australia.

Backswing: any movement produced by the athlete, in the clockwise direction. The movements produced by the athlete in the opposite direction of the force producing movements. The purpose of the backswing is to put all the necessary muscles on a stretch (Alexander, 2002).

- At the peak of the backswing, the athlete has rotated the trunk as far to the right as possible (clockwise direction), and both feet remain on the ground (Fig. 1-11).

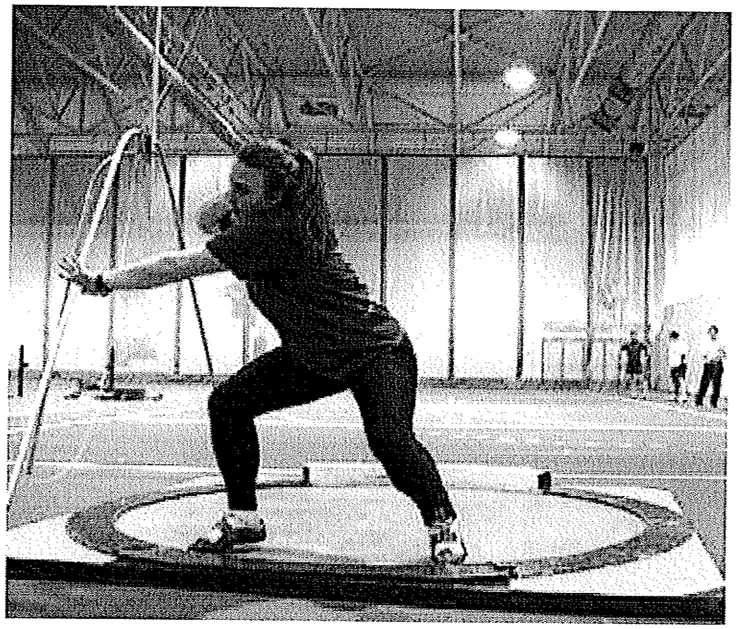


Fig. 1-11: Maximum backswing of a female rotational shot putter.

First double support phase: when the athlete has both feet in contact with the ground. The athlete is in the first double support phase from the starting position to when the right foot is removed from the ground (first single-support phase).

- The athlete uses the first double support phase to unwind the trunk and generate angular momentum in a counter-clockwise direction. The athlete remains at the back of the circle. This phase is part of the first turn.

First turn: begins immediately after completion of the backswing, the athlete is now producing force in the counter-clockwise direction. The second single-support phase represents the end of the first turn. The first turn includes the transfer of weight, the first single-support phase, leg kick, take-off and airborne phase and ends at the second single-support phase (Fig. 1-12).

- During the first turn, the athlete moves from the back of the circle to the middle of the circle while rotating approximately 360-degrees and first generating angular momentum.

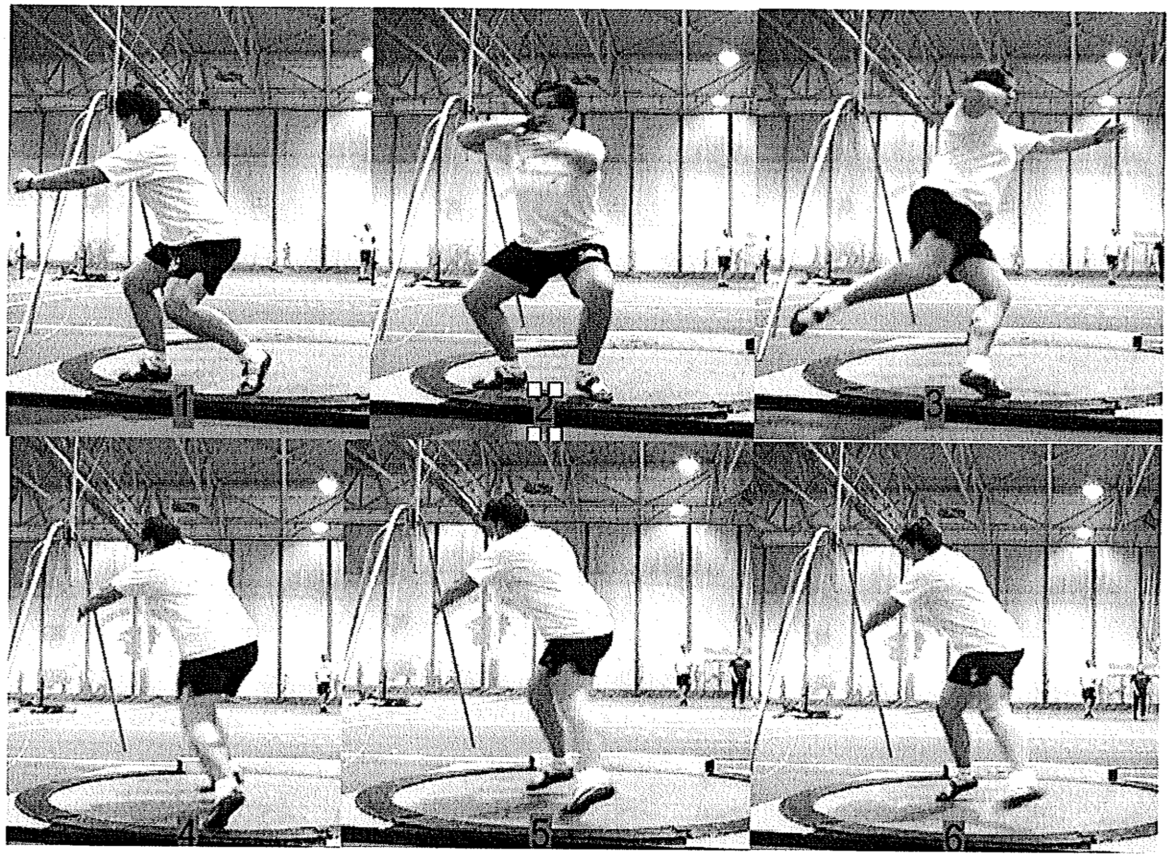


Fig. 1-12: Sequence picture of the first turn. The first turn begins at maximum backswing (1), includes a transfer of weight (2), first single-support (3), Take-off (4), an airborne phase (5) and ends at second double-support (6).

First single-support phase: for a right handed shot putter, the first single-support phase is the moment the right foot comes off the ground and is preparing for the "leg kick" and the athlete has transferred all of his/her weight onto the left foot in preparation for the first turn. This phase ends immediately after take-off when the athlete is airborne (see sequence picture number 3 in Fig. 1-12).

- Part of the first turn, the athlete is facing approximately 90-degrees from the original starting position and the athlete's weight is only supported by the left foot.

"Leg kick": when the right leg swings around the longitudinal axis of rotation to generate torque by abducting and flexing at the right hip and extending at the right knee. Lateral rotation of the right hip and dorsiflexion of the ankle also occur during this "kick" (Fig. 1-13).

- The athlete assumes a position with all of the weight on the left foot as the right leg controls and increases the rotation of the first turn.

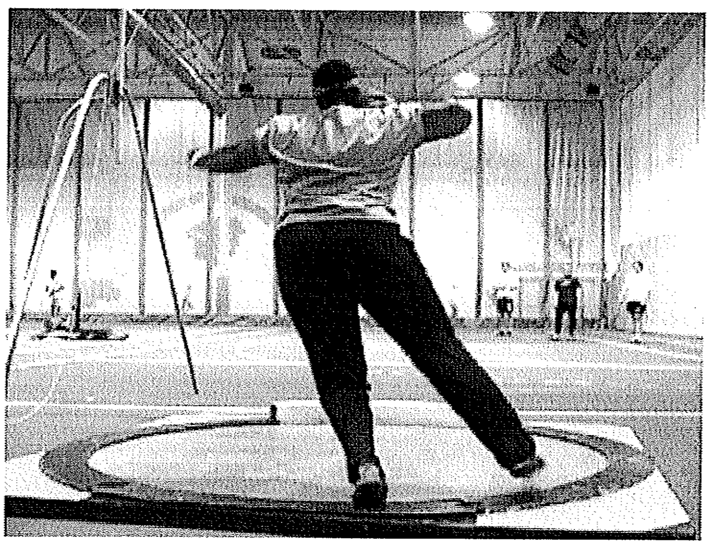


Fig. 1-13: Example of the "leg kick" performed by a female rotational shot putter.

Take-off: the instant the left foot leaves the ground.

- In this phase of the skill, the athlete has just finished pushing-off towards the middle of the circle and is airborne (refer to sequence picture 4 in Fig. 1-12).

Airborne: when the athlete is in the air and no body segment of is in contact with the ground (refer to sequence picture 5 in Fig. 1-12).

- While airborne, the athlete's aim is to remain balanced as the body continues to rotate in the air.

Touchdown: the moment the right foot makes contact with the ground. (Also referred to as the second single-support phase) (Refer to sequence picture 6 in Fig. 1-12).

- This is an important phase of the skill as the position of the athlete's body at touchdown is critical in determining the success of the throw.

Second single-support phase: Begins at touchdown when the right foot contacts the ground and ends when the left foot makes contact with the ground.

- The key to the second single-support phase is to maximize shoulder-hip separation and continue to rotate on the right toe. The shorter this phase, the better (see Fig. 1-14 sequence picture 1).

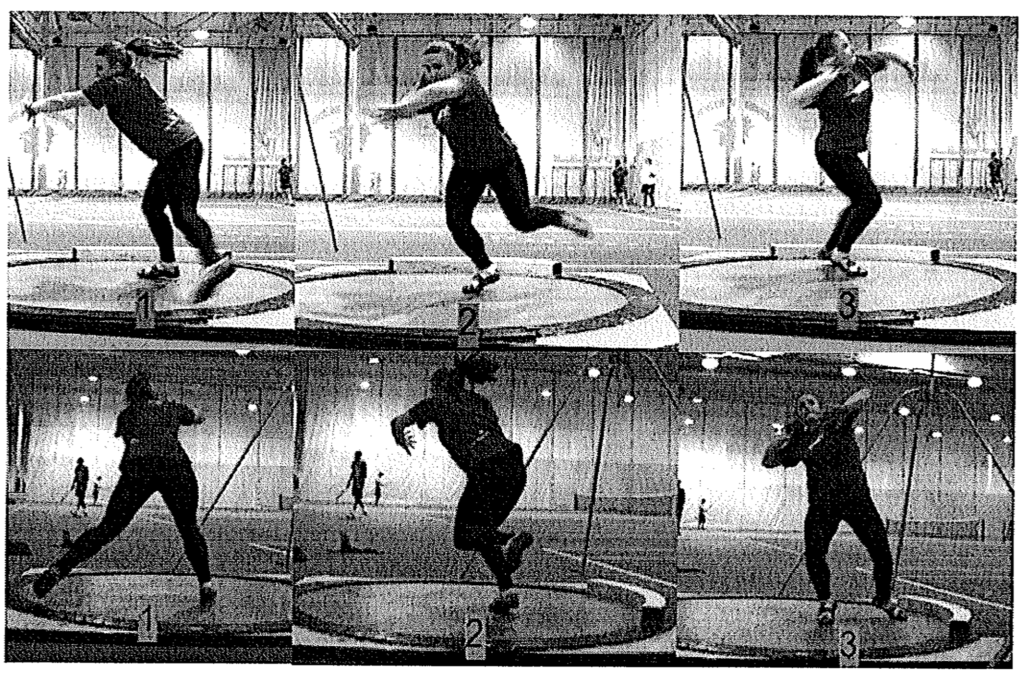


Fig. 1-14: Photo sequence of the second turn from the posterior view (top) and sagittal view (bottom). Second turn begins at second single-support (1), includes the free leg swing (2) and ends when the right foot touches down again at second single-support (3).

Second turn: begins at the second single-support phase, and ends at the second double support phase. The second turn includes the touchdown of the swing leg (the right leg involved with the "kick"), force-producing movements and touchdown of the left foot.

- In the second turn the athlete wants to accelerate the shot as fast as possible and maximize angular velocity of the body and linear velocity of the shot before release.

Shoulder-hip separation: when there is a difference between the orientation of the hips relative to the orientation of the shoulders (Fig.1-15). When the hips are ahead of the shoulders in rotation, this angle is positive. If there is no difference between the orientation of the hips relative to the shoulders then the angle is said to be zero – no separation is present (M. Young, 2004).

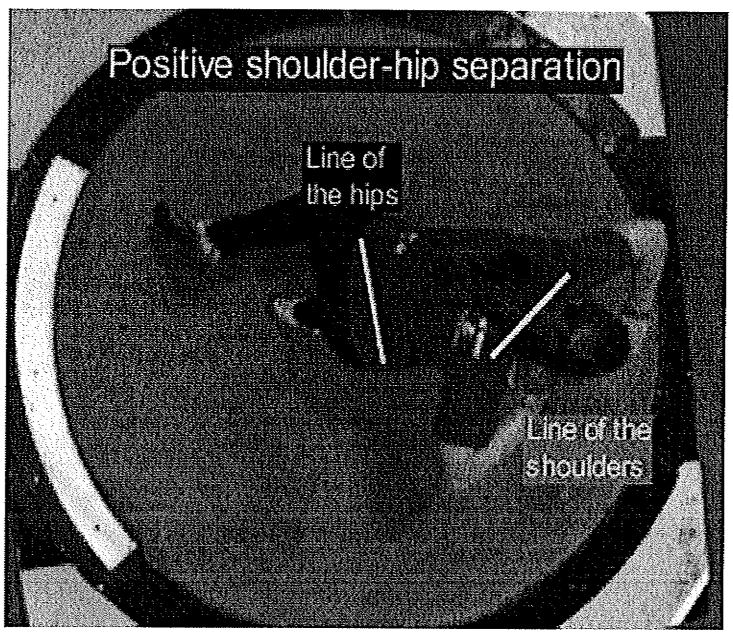


Fig. 1-15: When the line of the hips is ahead of the line of the shoulders the shoulder-hip separation is positive.

Second double support phase (power position): ends the second turn and occurs when both feet are once again in contact with the ground.

- In the second double support phase, the athlete assumes a position with both feet on the ground, more knee flexion in the right knee than the left, a flexed trunk and a positive shoulder-hip separation as the athlete faces the back of the circle.

Block: when the front foot during the second double support phase uses the toe board to help temporarily stop the hips from rotating.

- The athlete uses a block to stop the rotation of the hips so that momentum that was generated by the hips gets transferred to the upper body. The athlete uses the front left leg to block the rotation of the hips.

Critical Instant: occurs the moment the shot put leaves the hand and loses contact with the athlete.

- At this point, the shot should be moving its fastest as the fingers of the athlete's hand have just left the shot.

Reverse: occurs immediately after the critical instant. This is the follow-through for the shot put where the goal of the athlete is to decelerate all moving parts of the body to prevent injury and avoid falling out of the shot put circle.

- The athlete is typically airborne as the shoulders continue to rotate in a counter-clockwise direction and the back right leg comes forward as the left leg moves backward.

CHAPTER II
REVIEW OF LITERATURE

A review of literature has been conducted on four topics; the rotational shot put technique, the glide technique, physiological gender differences and Dartfish. First and foremost is a review of available literature on the rotational shot put technique which is broken down into the following phases: start position, backswing, force production, first turn, second turn, delivery and release and follow-through. A review of literature on the glide technique follows so the reader will have a better understanding of the technique that is currently used by the majority of women at the elite level in the sport. The glide technique is broken down into; start position, backswing, force production phase, delivery and release and follow-through. Physiological gender differences were then reviewed followed by a brief review of literature on the software program, Dartfish that was used to collect all of the data for this study.

ROTATIONAL SHOT PUT TECHNIQUE

Final release velocity, height of release and angle of release are the three main factors that determine the distance of a shot put (Hay, 1993; Pyka & Otrando, 1991; M. Young, 2004). Although release height is mostly predetermined by the height of the athlete and cannot be changed significantly, careful attention to the athlete's technique can greatly affect the final release velocity while biomechanics and mathematics has determined the optimal release angle for the shot put to be 31-36-degrees. As an athlete's technique is the most crucial aspect affecting the outcome of the throw, and the rotational shot put is a highly complex skill, the rotational shot put will be broken down and analyzed under the following subheadings: Start position, backswing, first turn, second turn, second double support and delivery, critical instant and the reverse.

Start position (Note: the following description applies to right hand throwers)

The start position will vary from athlete to athlete dependent on personal preference, body type and skill level (Fig. 2-1). In accordance with the rules, however, certain aspects of the start position will remain constant. The athlete will rest the shot on the base of the fingers (metacarpal-phalangeal joint) with the fingers slightly abducted to provide a large base of support for the shot, and will use the thumb for support only (Matson, 1983; Pagel et al., 2003). The shot should be tucked under the chin and in front of the shoulder, as the IAAF (2005) shot put rule 188.1 states, "shot shall be in close proximity to the neck or chin and the hand shall not be dropped below this position during the action of putting" (155). The legs should be shoulder width apart with the knees well flexed to lower the center of gravity and provide a large base of support to increase stability (Dziepak, ; Luhtanen, Blomqvist, & Vantinnen, 1997; Pagel et al., 2003; Pyka & Otrando, 1991; Rasmussen, 1998; Ward, 1975). As the athlete is at the edge of the back of the 2.135 meter shot put circle, a loss of balance could cause the athlete to step outside the circle and produce an invalid attempt (fault). The athletes should laterally rotate each hip so the toes are pointing slightly outward in order to allow the hips to rotate more easily through a larger range of motion (Pyka & Otrando, 1991; Rasmussen, 1998). The knees should be flexed 60 to 90 degrees (using the 180 degree system) depending on the preferred stance, with slight hip flexion to help keep the centre of gravity over the balls of the feet. Dorsiflexion of the ankles will occur naturally as a result of the flexed hips and knees, and the center of gravity should be over the balls of the feet and in the centre, between the feet in order to maintain balance.

The shot putter should be in a position with, "the chest over the knees over the toes" (Rasmussen, 1998). If the athlete is more prone to a high starting stance, a knee flexion angle between 40 to 60 degrees will be observed (Bartonietz, 1994). A high stance will be easier for athletes with larger torsos to rotate, and Bartonietz (1994) suggests that the athlete can then lower into the step allowing for loading of the muscles and a more explosive step to occur as a result. A low stance however, allows for a smooth controlled starting movement and allows for a continuous rise of the center of gravity throughout the rotation. This will help the shot follow a flat path during the airborne phase with no drop in the upper body with the step onto the right foot (Bartonietz, 1994). Foot placement in relation to the 2.135 meter throwing circle is usually described in terms of a clock – 12 o'clock at the front of the circle (middle toe

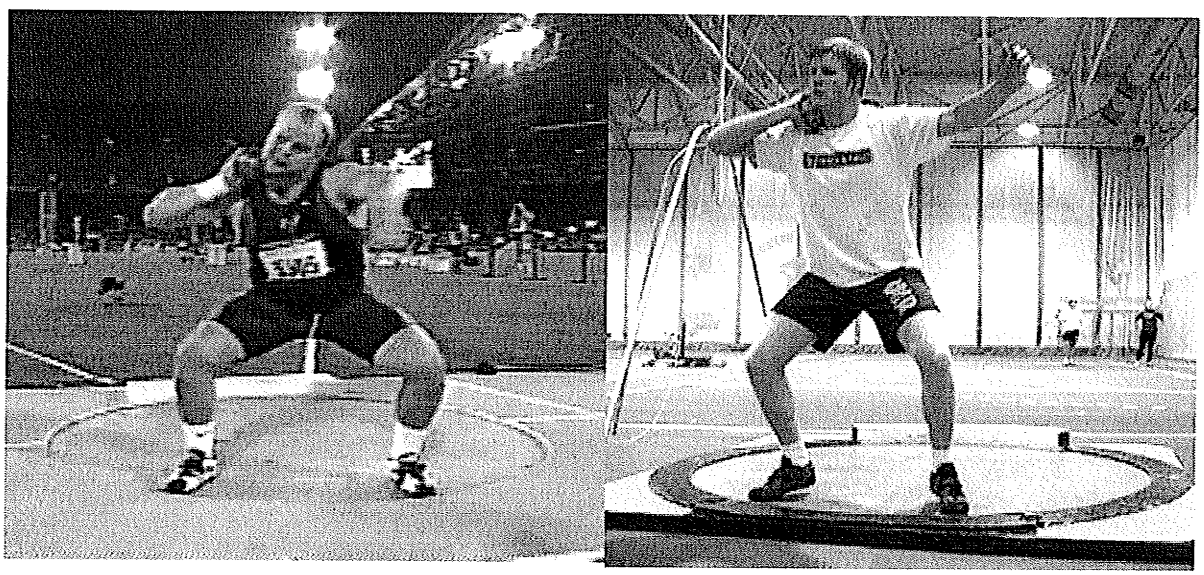


Fig. 2-1: Some shot putters prefer to start in a low position (left) while others chose to start from a more upright position (left).

board) and 6 o'clock at the back of the circle. At the start, world class shot putters tend to have their left foot close to 6 o'clock and the right foot close to 8 o'clock, nevertheless, foot placement will vary according to size of the athlete, skill of the athlete and personal reference. Finally, the left arm should be flexed 90 degrees at the shoulder and extended at the elbow (Ecker, 1978). The starting position is not usually a static position maintained by the athlete as any sustained tension can cause power loss (Koltai, 1975). A balanced position must be achieved prior to the backswing, in order to ensure that instability is not a problem throughout the throw.

Backswing

The purpose of the backswing is to "activate the stretch reflex in the muscles, as the muscles will contract more forcefully when they have been pre-stretched" (Alexander, 2002). Furthermore, the backswing will also increase the range of motion and time that forces can be applied during the force production phase (Alexander, 2002). In the shot put, the backswing includes all of the movements of the trunk and shoulders that occur away from the direction of the throw.

To initiate the backswing, the athlete must horizontally adduct the left arm (already abducted and parallel with the ground) and rotate the torso to the right to stretch the left side of the body. It is important to keep the shoulders level during this movement to prevent instability from occurring (Rasmussen, 1998). At the same time, the left knee extends to shift the center of gravity towards the right leg placing the quadriceps of the right leg on a stretch (Bartonietz, 1994) – allowing the left toe and knee to point in toward the right knee (Dziepak). The hips and the center of gravity should remain in the centre of the base - not directly over the right leg (Rasmussen, 1998) and the weight should be evenly distributed and balanced across both legs (Dziepak). Moreover, it is recommended that the athlete keep the right foot flat on the throwing circle at this point in order to prevent the athlete from going too far over the right side (Rasmussen, 1998).

There are two variations of the backswing, and the style chosen by the athlete for the starting position will determine which variation of the backswing will be used. If the athlete started off with a high stance, then the backswing will occur with the more upright

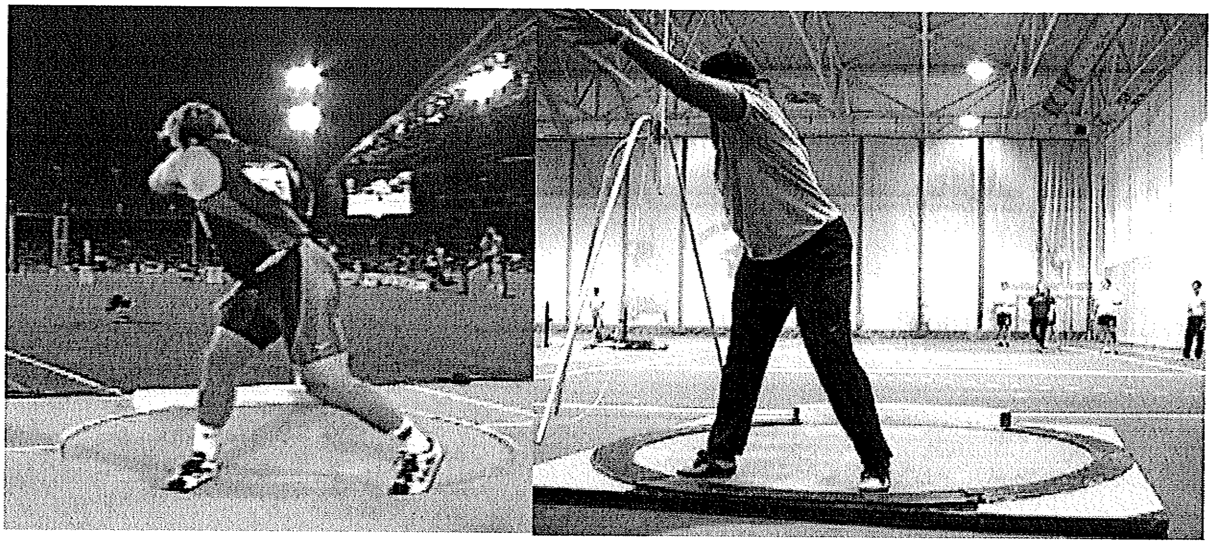


Fig. 2-2: Comparison of a relatively low backswing (left) to a high backswing (right)

position as well (Fig. 2-2). An athlete using the high stance will have less trunk and hip flexion with the axis of rotation going almost directly through the long axis of his head and trunk. Both knees will slightly extend and raise the center of gravity of the athlete and will eventually lead to a lowering of the center of gravity during the weight transfer to the left leg during the force producing phase of the skill. If the athlete has started with a relatively low position, then during the backswing, the knees maintain the same degree of flexion as in the starting position and there is no vertical displacement of the center of gravity as it follows a horizontal path. The benefits of a low stance include a continuous lift of the center of gravity without dropping the upper body onto the right foot during the right foot touchdown following the airborne phase. The more highly skilled the athlete, the greater the range of motion during the backswing phase of the skill. Immediately following the backswing phase is the Force Producing phase.

Force Production phase

The Force Production phase occurs when all the previously stretched muscles are maximally contracted in a sequential order to accelerate the body to produce the required movements (Alexander, 2002). During the Force Production phase of the shot put skill, the athlete must gradually increase the angular velocity while remaining balanced, and generate the greatest angular velocity possible while retaining body control, in order to produce the greatest release velocity of the shot. As the rotational shot put skill is complex, the Force Producing phase will be broken down into the "first turn" and "second turn" to simplify the analysis.

First turn

The main goal of the first turn is pre-acceleration and to produce optimal velocity and momentum (M. Young, 2004). The first turn dictates the rest of the throw, and any errors made here will significantly affect the outcome of the throw (Bartonietz, 1994; Luhtanen et al., 1997; Palm, 1991). Turning too fast during the first turn can lead to an unbalanced position and deceleration through the power position. "Starting rhythm and balance are critical factors in the rotation technique as balance and timing of the entry into the turn can affect the entire success of the throw itself" (Bosen, 1985). It is common for young athletes to increase rotational velocity prematurely, which often leads to instability, technical problems, decreased muscle loading or inefficient sequencing of muscle contractions.

The first part of the Force Production phase is the transfer of weight from the right leg to the left leg. The shoulders should be kept level and the upper body stable as the left arm, shoulders and torso rotate counter-clockwise together as one single unit (Bartonietz, 1994; Pagel et al., 2003; Palm, 1991). "The left toes, knee and arm must sweep and rotate left" in unison (Dziepak). A common error in many rotational shot putters is allowing the left arm to lead the turn instead of having the left side turn as a single unit (Fig. 2-3). This error in technique causes the athlete to rush through the first turn and creates a shoulder-hip separation, with the shoulders leading the hips, which is the opposite of what needs to be obtained later in the throw. If possible, the athlete should strive to leave the right hip behind during the weight transfer to the left leg in order to put the right hip on a stretch to load it for the leg kick to follow (Bartonietz, 1994). However there is not universal agreement on this point.

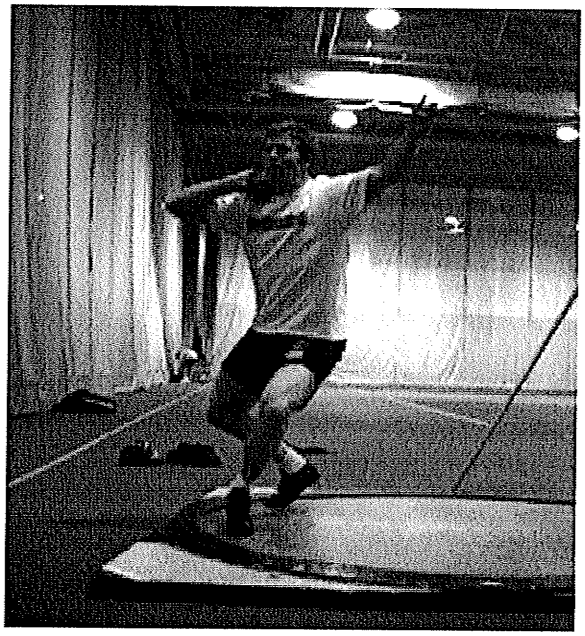


Fig. 2-3: This young shot putter incorrectly leads the turn with his left arm. At this point in the skill, the arm and thigh should be pointing in the same direction.

During the weight transfer, there should not be too much trunk lean. It is better to have more knee flexion than excessive trunk lean as too much trunk lean can create too large a moment of inertia (resistance to rotation) around the vertical axis, slowing the turn down too much. Sufficient torque can be generated by an effective leg kick therefore there is no need to use the upper body to generate torque. The left shoulder should be abducted 90 degrees and the elbow slightly flexed to help keep the upper body balanced and help control the turn, as the position of the left arm can be changed to either speed up the turn or slow it down. By extending the elbow the radius of gyration increases creating a larger moment of inertia around the vertical axis which decreases angular velocity. This is assuming angular momentum stays relatively the same. Flexing the elbow will increase the angular velocity as the moment of inertia is decreased due to the decrease in the radius of gyration. The abduction of the left shoulder also helps balance the higher torque on the right side that is created by the extra weight of the shot (Steben & Bell, 1978) that could cause the shoulder girdle to tilt in the direction of the shot. Furthermore, it has been suggested that the arm abduction also helps keep the athlete from prematurely leaning backward (Pagel et al., 2003).

To transfer the weight to the left leg, the right ankle should plantarflex, the athlete should not extend the right knee (Bartonietz, 1994). Extending the right knee will decrease the effectiveness of the leg kick in generating torque. Push-off from the right leg (via right ankle plantarflexion) is accompanied by rotation on the ball of the left foot (Pagel et al., 2003). Another common source of error in young rotational shot putters is rotation occurring on a relatively flat foot that will unnecessarily slow down the rotation. During the weight transfer, the center of gravity will shift behind the left foot toward the center of the circle. During the weight transfer, the left knee should remain flexed in a position as close to 90 degrees as possible. The left quadriceps muscles will be contracting eccentrically as they are stretched, allowing for the muscles to increase stored elastic energy that will increase the force output. The feet should be the same distance apart at this point as they were in the starting position (Pyka & Otrando, 1991). Once the transfer of weight is fully on the left leg, the right foot comes off the ground and the athlete is now in single-support.

During the single support phase, the angular difference between the hips and the shoulders should be approximately 20 degrees by the right leg takeoff (hips preceding the shoulders slightly to put tension on the right hip) (Bartonietz, 1994). However, several top rotational shot putters tend to keep the trunk square with no lag between the shoulders and the hips during this phase. The left shoulder and left knee should turn together. As the left knee turns, rotation takes place on the ball of the left foot and at this time, there is no longer an observed twist in the torso, the hip-shoulder angle differentiation is near zero.

The right leg kick then follows with its purpose to generate angular momentum in the leg that will be transferred to the trunk. The leg gives an angular impulse to the thrower's body towards the middle of the circle (Bartonietz, 1994). The hip should be slightly flexed and the knee flexed approximately 90 degrees. The knee extends before hip extension and begins when the body is facing between 2 and 3 o'clock. The extension of the right knee increases the moment arm for the weight of the leg, resulting in an increase in torque about the vertical axis, providing the force remains constant. If the knee is extended too early during the transfer of weight to the left leg then the radius of gyration is increased and the moment of inertia is increased. This will result in a decrease of angular velocity very early with the lower leg unable to generate any angular velocity of its own to apply an impulse to the upper leg and eventually the hips and the rest of the body. Rotation should still be taking place on the ball of the left foot

(Bartonietz, 1994; Pagel et al., 2003). Once the right knee has fully extended, the right hip then flexes as the right leg sweeps across.

In the leg kick it is not uncommon to see some athletes with their right hip laterally rotated and the ankle close to anatomical position with the toes pointing upward. This position will increase the moment of inertia about the vertical axis of the trunk and increase the angular momentum it can generate and help the athlete control the speed of the turn. In consequence, the right leg starts behind the trunk, and then accelerates to a position in front of the trunk and then stops. When the right leg stops, it transfers its angular momentum to the trunk (Alexander, 2004).

There are two different variations in the direction of the leg kick. In the more common variation number one, the right knee drives down (Pagel et al., 2003; Pyka & Otrando, 1991) by keeping it very close to the left leg with very little, if any hip abduction. This will ensure a flat airborne phase with minimal airtime so ground reaction forces can be applied to the throw sooner. By keeping the right leg in close to the left leg, the moment of inertia will be decreased which will likely increase angular velocity and decrease the time it takes for the overall throw.

Variation number two incorporates abduction of the right hip to help generate more torque to increase angular momentum when it stops at the end of the leg swing. This, however, will increase the moment of inertia and will decrease the angular velocity if angular momentum remains constant. It has been observed however that, "this looping sweep of the left leg appears to create considerably more momentum than keeping the left leg low . . ." (Pagel et al., 2003). Rasmussen (1998) also recommends a wide sweeping leg. Furthermore, a greater shoulder-hip separation for the power position can be achieved with a wider leg kick, and there is a strong, positive correlation between shoulder-hip separation and the final horizontal distance of the throw (Goss-Sampson & Chapman, 1997).

Independent of the leg kick technique used, the right knee then flexes for preparation of the right foot contact with the throwing circle. Flexion of the right knee is optimal to maintain a low starting position that will allow the greatest range of motion possible for the final force producing movements (vertical acceleration of the shot). The importance of the right leg kick in generating torque is very large, but the forceful push off from the right leg push also contributes to generating torque. A poor leg kick will result in less torque being generated that in turn, will decrease the angular velocity and slow the rotation on the ball of the left foot. At this stage of the rotational shot put skill it is important to keep in mind the angular analogue of Newton's second law of motion.

During the take-off phase, the upper body should remain stable for a more effective push-off. If the upper body does not remain stable, then the forces produced from the powerful knee extension will be absorbed by the upper body. "The athlete must think of being active with the lower body and passive with the upper body" (Rasmussen, 1998). Rasmussen (1998) further noted that separation of the hips and shoulders "is maintained when the athlete keeps his shoulder and chest facing in the direction of the sector just prior to his left leg pushing off the ground" (p.17).

The next part of the Force Production phase is actually the one point where force cannot be applied – the airborne phase. At this point in the skill, the athlete has, "initiated the necessary torque between the arms and torso and the hips and legs" (Pagel et al., 2003). Once the athlete is airborne, angular momentum remains constant within the system and no additional torques can be applied. Torques can only be applied to the ground while in contact with the ground. For this reason, the airborne phase should be as short as possible (Bartonietz, 1994; Palm, 1991) as short throws (compared to long throws) exhibit longer flight time (M. Young, 2004). Therefore, the less time spent in the air, the more time the athlete can spend on the ground applying torque. In other words, the right swing leg would be better utilized on the ground generating the acceleration of the shot in the direction of the throw. The athlete should also focus on moving his/her center of gravity in a horizontal path rather than a vertical path (Bartonietz, 1994).

Excessive vertical velocity while airborne provides no benefit to the athlete. Too much vertical velocity can lead to poor mechanics at right leg touchdown and is wasted energy that could be better utilized elsewhere (Alexander, 2004). "Right knee flexion at impact following the rotation phase was also negatively correlated with distance. This flexion may in part break the forward velocity of the thrower and delay

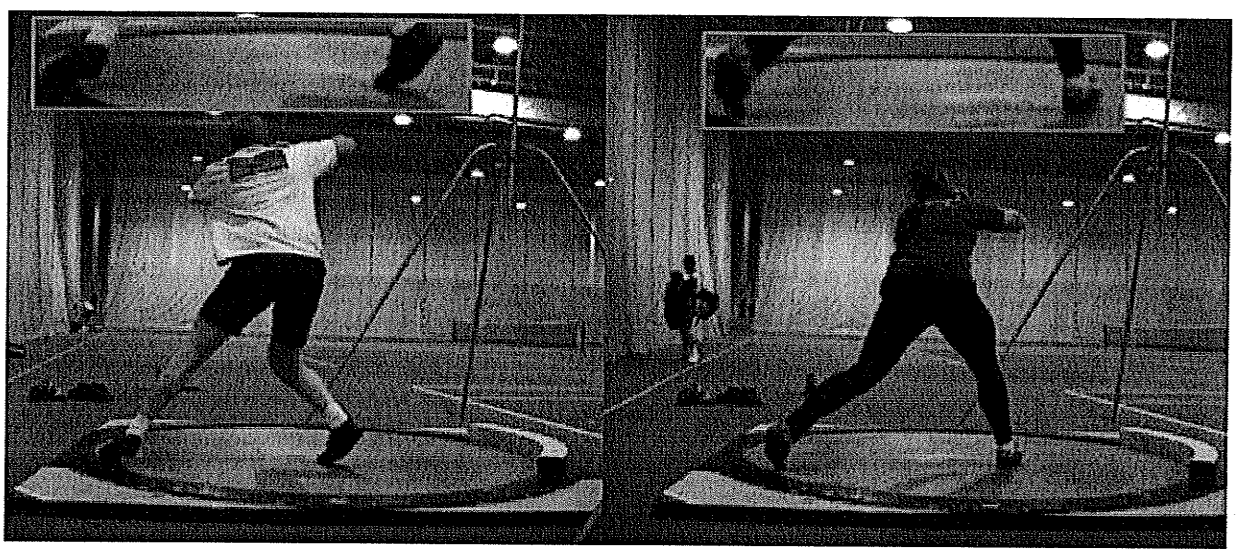


Fig. 2-4: Neither one of these athletes has an airborne phase. Both of them step into the circle.

the rotation to delivery transition" (Goss-Sampson & Chapman, 1997). With that being said, the airborne phase must be airborne – if this phase becomes more of a step and not a flight phase, then angular velocity will be decreased (Bartonietz, 1994) (Fig. 2-4). Controlling the speed of rotation during the airborne phase is accomplished by keeping the left shoulder flexed and left elbow extended and laterally rotating the right hip.

Second turn

When the leg touches down within the shot circle, the athlete is now in the second single-support phase and is now starting the second turn. The right foot should be planted just past the midline of the circle (Pagel et al., 2003) leaving a shorter distance to the toe board that is optimal for achieving more vertical displacement of the throw. The vertical displacement of the throw is important in determining the overall horizontal distance of the throw. Once the shot leaves the athlete's hand, it becomes a projectile and projectile equations apply. Increasing the vertical distance the shot is from the throwing circle will lead to a greater vertical distance traveled by the shot which in turn will increase the time in the air. An increase in time in the air will result in a greater horizontal distance of the shot (ignoring air resistance). If the final base of support is too wide, then there is less vertical acceleration of the right leg and less vertical displacement of the shot prior to critical instant that will lead to a decrease in potential horizontal distance. The

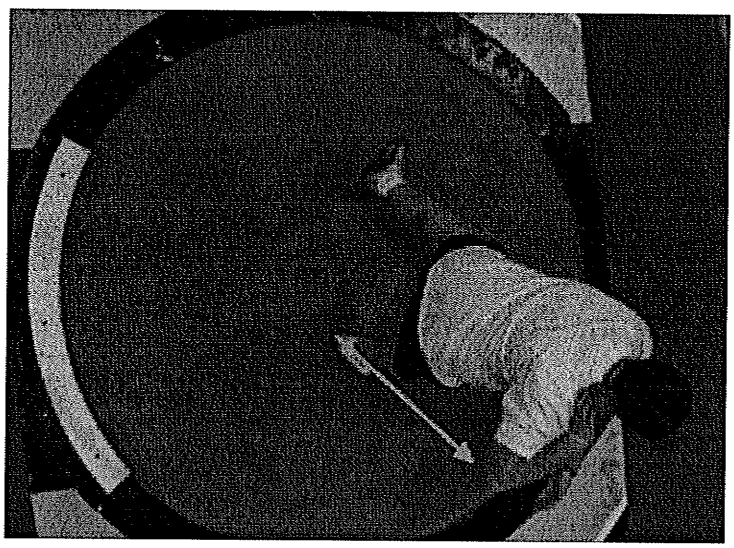


Fig. 2-5: Athlete lands in the circle with her foot pointing towards 8 o'clock.

athlete should land on the ball of the right foot pointing between 7 and 9 o'clock in a low position (right knee flexed approximately 60 to 80 degrees (Bartonietz, 1994) with the athlete's center of gravity over the balls of the right foot (Fig. 2-5). If the foot lands at seven o'clock then it decreases the range of motion of the trunk during the throw, decreasing the angular velocity. If the foot lands at 10 or 11 o'clock then there is too much rotation still to occur in order to get into the appropriate position. In this instance, friction between the ball of the right foot and the ground will slow the rotation, decreasing angular velocity and ultimately reducing the linear velocity that can be achieved on the shot. It is important that there is no pause or delay of rotation on the ball of the right foot – rotation should remain continuous (Pagel et al., 2003; Palm, 1985; Rasmussen, 1998) (see Fig. 2-6). A pause in the rotation around the right foot at touchdown indicates that not enough torque was generated by the right leg kick. Consequently, the pause in rotation will lead to late planting of the left foot and the hips will not come through effectively.

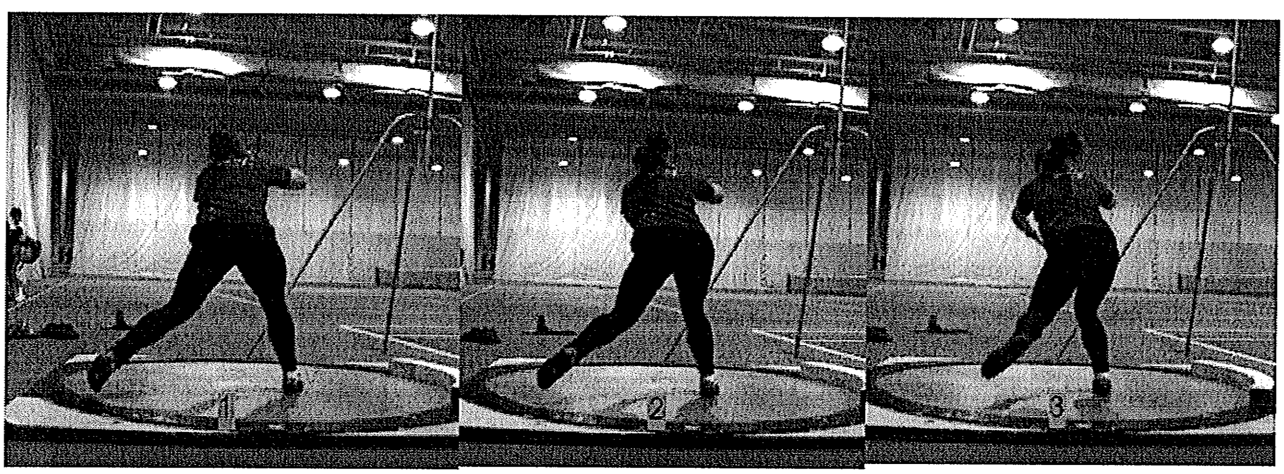


Fig. 2-6: Pictures 1 shows the shot putter landing just past the midline of the circle flat-footed with her toes pointing towards 10 o'clock. Pictures 2 and 3 show a change in position of the body and only a minimal amount of rotation occurring on her pivot foot.

As mentioned earlier, there should be no increase in trunk flexion when the right foot touches down, and also very little – if any, increase in knee flexion (Pyka & Otrando, 1991; Sampson & Chapman, 2002). Knee flexion near 70 degrees is ideal (Dziepak, 1998 suggests 75 degrees is ideal) as this will place the quadriceps on a sufficient stretch as they contract eccentrically with the hip extensors and plantarflexors, and allow a great range of motion through which force can be applied. It is important that the flexion increase in the right knee on touchdown is minimized, otherwise an obvious "piston" like action will be observed in the right knee. This will require a great deal of energy from the quadriceps (extremely high eccentric contraction that can cause injury) and less energy will be available for the final vertical acceleration of the shot. An excessive increase in knee flexion can indicate that too much vertical velocity and consequently, vertical displacement was obtained in the airborne phase. However, the maximum knee flexion angle that can be achieved is dependent primarily on the strength of the athlete.

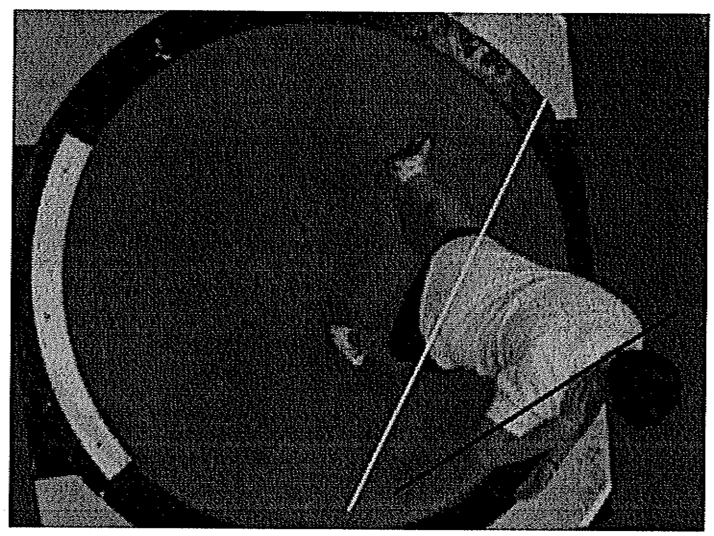


Fig. 2-7: At right foot touchdown (second sing-support) the athlete has a significant shoulder-hip separation. This places the trunk muscles on a stretch-similar to the twist in her shirt.

The athlete should land in a position where there is an angular difference in the frontal plane with the hips leading the shoulders (Bartonietz, 1994) (Fig. 2-7). The importance of this separation cannot be emphasized enough. As the right foot touches down, the hips rotate around the longitudinal axis as the shoulders and shot remain facing posteriorly to create a stretch in the left side of the body (Dziepak, 1998). The inertia of the shot will help keep the upper body facing posteriorly (Bartonietz, 1994). The hip line – shoulder line separation allows for the abdominal muscles, back muscles and shoulder girdle to be put on a stretch and maximizes the range of motion the shot can travel while having forces from the large trunk muscles applied to it (Aleaxander, 2004). The left side of the upper body should remain horizontally adducted for as long as possible, giving the illusion that the left arm remains stationary upon right foot touchdown as the rest of the upper body catches up to the arm. The, "left shoulder must continue to delay the rotation of the upper body until the left foot grounds" (Rasmussen, 1998).

As rotation is taking place on the balls of the right foot, the left leg is still airborne until it touches down for the delivery phase. There are two schools of thought regarding the role of the left leg. The more traditional strategy used is "shorten all levers" (Bartonietz, 1994; Luhtanen et al., 1997; Pyka & Otrando, 1991; Rasmussen, 1998; Steben & Bell, 1978). The biomechanical principle supporting this technique states that by shortening all levers (mainly the left leg at the knee and hip), the moment of inertia will decrease allowing for a faster angular velocity to be achieved. The left knee flexes and the left hip adducts (if not already) and swings close to the right knee. This will decrease the moment of inertia about the vertical axis and increase angular velocity helping to plant and brace the left leg as soon as possible. This requires less energy to be exerted by the athlete to bring the leg down and around to the second double support phase. In comparing short throws to long throws, "short throws exhibited longer flight time for the left leg during rotation phase" (Goss-Sampson & Chapman, 1997).

However, when supporting a long sweep of the right free leg (during the leg kick going into the airborne phase), and briefly mentioning the left leg sweep, Young (2004) states that, "a wide sweep of the free leg will help to maximize the rotary momentum of the rotational thrower . . . and will assist in developing greater positive separation between the shoulders and hips at rear-foot touchdown". The sweep of the left leg will contribute to rotary momentum of the hips during the left leg sweep just as the right leg sweep contributed earlier. The 2002 United States National shot put champion and 2004 Olympic silver medalist Adam Nelson uses a more unique left leg sweep to generate

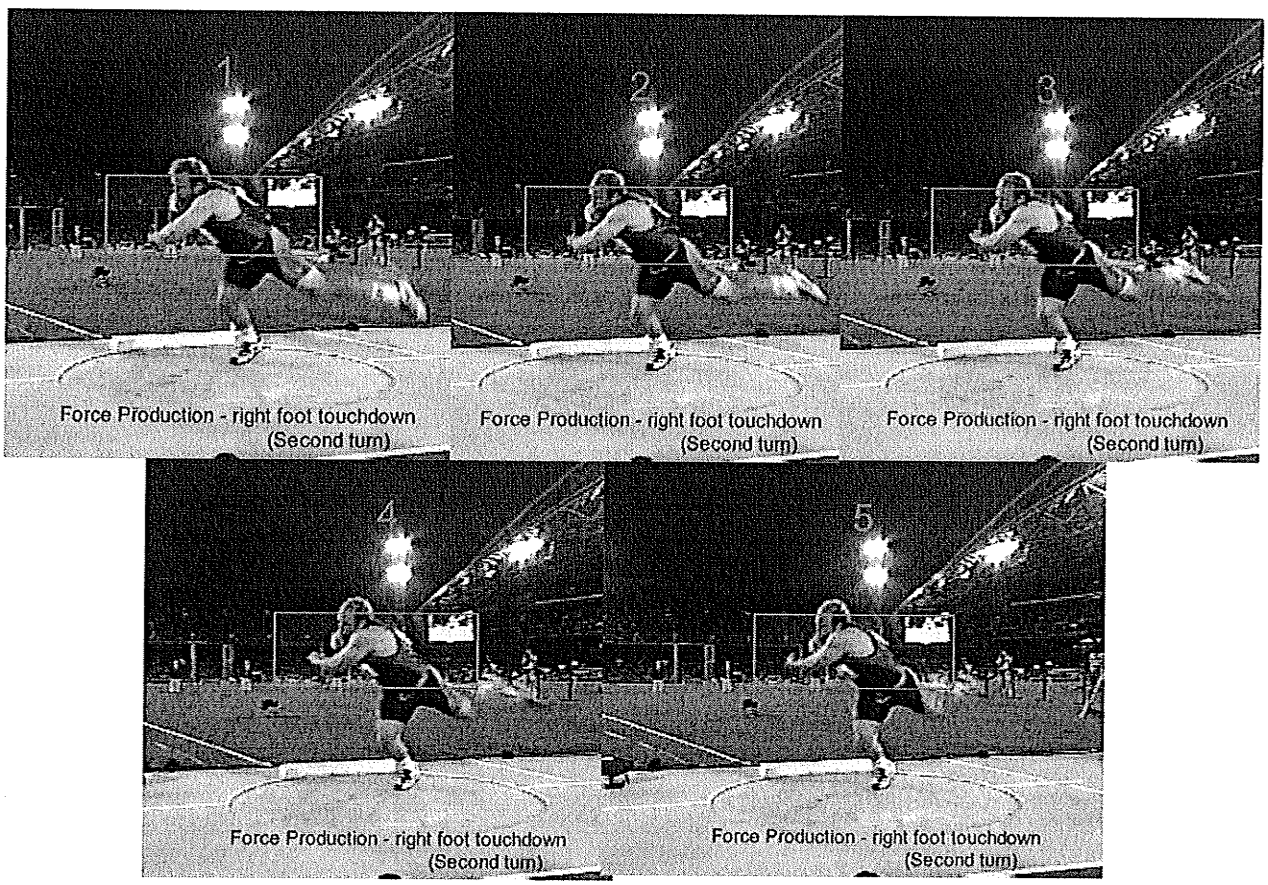


Fig. 2-8: Adam Nelson uses a wise leg sweep during the second turn. This position helps him create a greater shoulder-hip separation and places his trunk muscles on a very large stretch. An athlete must be flexible in order to use this technique.

angular momentum via forceful left hip extension, left hip abduction and left hip lateral rotation which applies a torque to help increase angular momentum of the body during the delivery phase (see Fig. 2-8). "This looping sweep of the left leg appears to create considerably more momentum than keeping the left leg low . . ." (Pagel et al., 2003). This technique can produce a much greater stretch of the abdominals and obliques that are extremely important in producing the forceful trunk rotation during the delivery. Although this technique requires strong gluteals and lateral hip rotators and excellent flexibility, the results can contribute greatly to the overall angular momentum that can be generated on the second turn.

There should be a forty to sixty degree difference between the hip line and the shoulder line just prior to bracing the left foot (Bartonietz, 1994; Luhtanen et al., 1997). The shoulder-hip separation is important, as the greater this separation, the greater the torsion between these two body segments, and the greater the accumulation of stored elastic energy that can be released at critical instant (Coh, 2005; Dyson, 1973). It has been suggested that a greater shoulder-hip separation is positively correlated with distance thrown (Sampson, 2002). It is important that the hips continue to rotate through the power position in order for the hips to lead the throw and the athlete should focus on planting the left foot as soon as possible for the block to occur (Bartonietz, 1994; Pyka & Otrando, 1991; Steben & Bell, 1978). If planting of the left leg is late then the hips do not come through quickly enough and optimal tension on the left side of the body is not reached, thus, decreasing the angular velocity that could have been generated.

The left foot should be planted as close to the toe board as possible (Bosen, 1985) near the center (Ecker, 1978) and the athlete should focus on trying to get the left heel down for an effective block. Although the heel most likely will not fully land, the lower the heel comes to the ground, the more effective the block will be. If the athlete plants the left foot on the ball of the foot, the foot continues to rotate and the necessary impulse required to briefly stop the hips from rotating cannot be applied. Without an effective block, the shoulders will not be able to catch up with the hips and angular momentum will not be transferred effectively to the shoulder girdle. In contrast, new studies show that maintaining the angular velocity of the trunk throughout the delivery is more effective than blocking the left side prior to delivery. This ensures that force is still being applied to the shot and that no early deceleration of the shot is occurring (Sampson, 2002).

Fig. 2-9: An example of the second double-support phase. Note the position of the feet in relation to the circle.

The left foot should be planted with slight knee flexion so a double knee and hip extension can take place to increase the vertical lift of the center of gravity of the athlete and shot (Fig. 2-9). A narrow position of the feet at second double support will help decrease the moment of inertia about the longitudinal axis and allow for a higher release point at critical instant as the center of gravity of the athlete and thus the shot will be higher (Bartonietz, 1994). A narrow final stance (no greater than shoulder width apart) during the second double support phase, is also supported by Pagel et al. (2003). A wider position of the feet in the second double support phase gives better possibilities for the bracing effect of the left leg and will also decrease the range of motion through which the athlete can apply force in the vertical direction.

Delivery and release

During the delivery, the center of gravity should be shifting over the left leg following the powerful drive from the right hip and knee; however these joints remain flexed as the hips continue to rotate forward. Hip rotation to the left is likely produced by the forceful pulling of the abdominals rather than from the extension of the right leg (Alexander, 2004). "The function of the legs during the delivery is to manage the straightening the body with a heave-up push to give the base for the powerful trunk turn . . . These actions create the first part of the final shot acceleration" (Bartonietz, 1994).

Many researchers disagree that the rotation of the torso contributes more to the acceleration of the shot than the legs. Luhtanen et al. (1997) suggest that the "primary power is generated in the form of ground reaction forces as a result of the leg action" and is supported by Palm (1978). Both the action of the legs and the action of the torso are necessary to generate the acceleration of the shot – both make an important contribution. Many elite shot putters do not fully extend their right knee by the time the shot is released. If extension of the legs were the only contributor to the acceleration of the shot, then the back leg should be fully extended in order to maximize the force that can be generated from this movement. Immediately following left foot touchdown, the hips continue to follow-through as the ball of the left foot acts like a "pivot" and the shoulders begin to forcefully rotate using the stored strain energy in the muscles of the trunk and hips. The horizontally adducted left arm then forcefully abducts horizontally to increase torque from the shoulder and help drive the shoulder girdle around to the direction of the throw (Fig. 2-10). The abduction/flexion of the shoulder helps raise the shoulder girdle that will help the shoulders rotate through a full range of motion more easily – similar to why a baseball pitcher abducts his/her arm and the shoulder-hip separation decreases. The "left arm is then pulled around in an arc on the same plane that you will put the shot" (Matson, 1983). Eventually, the left arm stops around eleven o'clock and transfers its angular momentum to the whole trunk (Pagel et al., 2003). The throwing elbow joint starts to forcefully extend at almost the exact moment when the shoulder axis rotates over the hip axis (shoulder-hip separation is now at zero). At this time, "the implement should be placed in a position of maximum leverage away from the body" (Rasmussen, 1998) as much as is permitted by the rules. The increased separation between the shot and the neck (spinal axis is the axis of rotation) will increase the moment arm and increase the torque that can be applied to the shot.

Fig. 2-10: At release many elite athletes are airborne at release and the shoulder-hip separation is almost zero as the shoulders catch up to the hips. Notice the flexion remaining in the right knee at release.

Briefly mentioned earlier, the left leg extends forcefully during the delivery of the shot to produce force for the vertical elevation that occurs at release; the right leg is already unweighted and so does not contribute to the vertical velocity at release (Alexander, 2004) (Fig. 2-10). At this point in the delivery, there is a slight horizontal movement of the center of gravity to the left as the right hip laterally rotates throughout the knee extension (Luhtanen et al., 1997). Although the athletes should strive for complete knee extension, slight flexion of the knee at second airborne phase can be indicative that the initial force generated by the legs accelerated the athlete so rapidly that the athlete becomes airborne before full extension can occur (Young, 2004). In this case, further knee extension would not further accelerate the athlete. Once the shoulders are square to the direction of the throw, the right elbow completes its extension bringing the shot off the shoulder simultaneously with horizontal adduction of the shoulder joint (Bartonietz, 1994). Many less skilled athletes make the error of using shoulder flexion with the elbow extension. This is common when young athletes move up to the senior men's or women's heavier shot. Afraid of dropping the shot, young athletes place their thumb underneath the shot to "prevent it from slipping" causing the arm movement to occur in the sagittal plane as opposed to the more correct transverse plane (Fig. 2-11). There should only be elbow extension, shoulder horizontal adduction and medial rotation of the

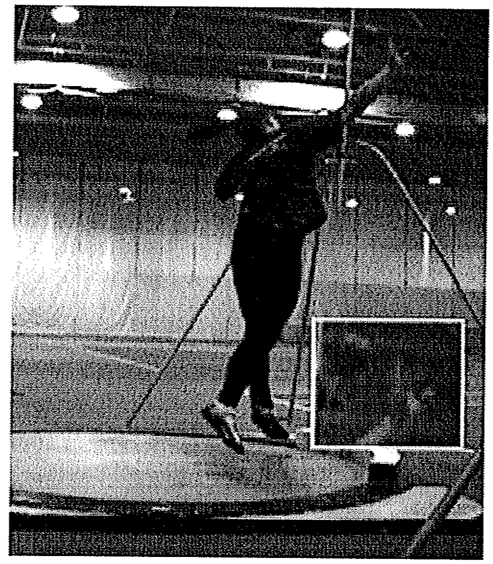


Fig. 2-11: This athlete releases the shot in the sagittal plane rather than the transverse.

shoulder observed. The right elbow reaches maximum extension just after maximal left knee extension when the athlete is in the second airborne phase.

The final movements that occur prior to the release of the shot are flexion of the right wrist and pronation of the right forearm. The fingers of the right hand remain extended as the shot rolls off the fingertips and the left arm should remain abducted at 90 degrees through the release allowing the shoulder girdle to rotate freely. The athlete should have reached maximal vertical velocity (via hip and knee extension and plantarflexion of the ankle) to ensure that the athlete has utilized all the angular velocity generated, to help produce the release velocity of the shot. A release angle between 31 and 36 degrees is optimal for most throwers (M. Young, 2004) as opposed to the ideal mathematical release angles of 40 to 42 degrees. The theory is that it is easier for the athlete to generate maximum force on the shot at the lower release angle that will result in a greater release velocity (elite shot putters release the shot with a velocity in excess of 13m/s) (Bosen, 1985; Coh, 2005; M. Young, 2004). Each athlete has his/her own specific optimum release angle because of individual differences in the rate of decrease in release speed with increasing release angle (Linthorne, 2001).

The release of the shot should occur between 0.2m and 0.5m in front of the toe board (M. Young, 2004). By releasing the shot in front of the toe board, the athlete will have maximized the horizontal distance of the shot. This distance from the toe board contributes to 2-3% of the final distance, not including the extra distance that can be achieved as the athlete can accelerate the shot over the maximal range of horizontal motion (M. Young, 2004). In addition, a neutral shoulder-hip orientation at critical instant is observed in the world's best throwers, indicative of a strong block of the left side (Fig. 9). This increases the velocity of the right side and the shot, as all the angular momentum is transferred from the body and shoulder girdle to the throwing arm. However, the shoulder girdle is not stationary – the shoulder girdle never stops rotating throughout the throw! This is why the timing of movements is critical to the rotational shot put technique. "The (rotational shot put) technique involves complex movements performed at a relatively high speed in a limited space" (Luhtanen et al., 1997).

Follow-through

Following the release of the shot, the athlete must now slow down the rotation and all the limbs in a safe controlled manner to prevent injury and to prevent stepping out of the circle prematurely (faulting). The right side should be facing the direction of the throw and the left leg moves posteriorly (Pagel et al., 2003). The extended right leg is then planted against the toe board (although Rasmussen says it should never touch the toe board (1998)), and acts like a brace (Bartonietz, 1994). The body is extended with the right knee locked out and the right shoulder and right arm high (raising the center of gravity) (Pagel et al., 2003). The athlete then needs to extend the left leg up towards the back of the throwing circle with the left arm to lengthen the levers (Pagel et al., 2003; Pyka & Otrando, 1991), increasing the radius of gyration and ultimately increasing the moment of inertia and decreasing angular velocity (the athlete's rotation) (Fig. 2-12). The shoulder should lead the hips in the follow-through while maintaining a shoulder-hip separation indicating that the shoulder rotation did not decelerate prior to the throw. Observation of the follow-through can indicate to a coach which errors took place during the skill. The follow-through is much easier for rotational shot putters than it is for gliders using the O'Brien technique.

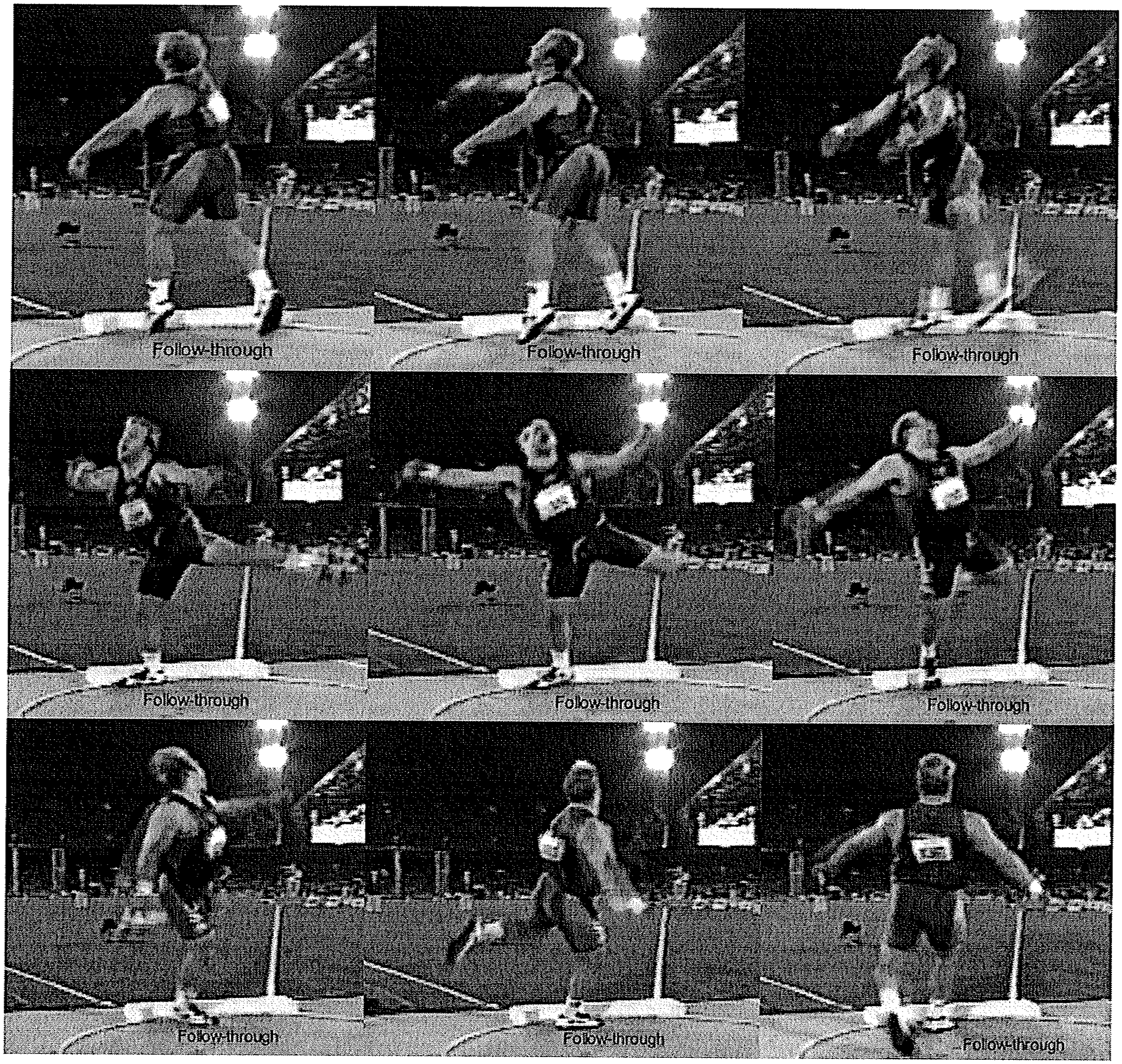


Fig. 2-12: Follow-through sequence of an elite rotational shot putter. All limbs are extended as the right leg comes forward and the left leg moves backward – this is what is referred to as a “reverse”.

GLIDE TECHNIQUE

Start position

Similar to the rotational shot put technique, the athlete begins facing the back of the circle; however the athlete's feet are oriented in an anterior-posterior position as opposed to the side-by-side orientation. The toes of the front right foot should be pointing away from the direction of the throw and be close to the rear edge of the circle (Hay, 1993). The left foot rests on the circle a short distance behind the right foot and helps the athlete reach a state of equilibrium (Hay, 1993). The position of the trunk can vary. Some athletes will keep their trunk upright and extended and wait to flex their trunk in the backswing phase. Others will flex their trunk in the starting position as they acquire their balance and then extend and flex their trunk again. In either case, the athlete's weight should all be on the right leg. The left arm remains relaxed and in a near-vertical position and the shot is held in the same position as described in the rotational shot put technique.

Backswing

The backswing of the glide is primarily the loading of the right leg. The right knee should be flexed to 90-degrees at the maximum backswing and all of the athlete's weight should be over this leg (Fig.2-13). The deep knee flexion places the quadriceps on a large stretch that initiates the stretch reflex in the muscle which contributes to the force of knee extension. Furthermore, the greater the knee flexion, the greater the range of motion through which knee extension can occur. The greater the range of motion of knee extension, the greater distance that the athlete can apply force, the greater angular velocity at the knee joint the athlete can generate and the greater the impulse the athlete can apply to the ground. The trunk on the other hand should also be flexed and parallel to the ground. The flexion of the trunk serves two main purposes: it places the shot in a position outside the back of the circle which "increases the distance through which the athlete may exert force on it" (Hay, 1993) and it stretches the trunk muscles that will later permit the muscles of the back to make a substantial contribution to the release velocity of the shot (Hay, 1993). An additional benefit to flexing the trunk is that it shifts the centre of gravity closer to the back of the circle which increases the distance the centre of gravity can move across the circle. Once balance is obtained, the athlete then flexes the left hip and knee and brings the left leg under their centre of gravity in a final attempt to maximize the loading of the right leg.

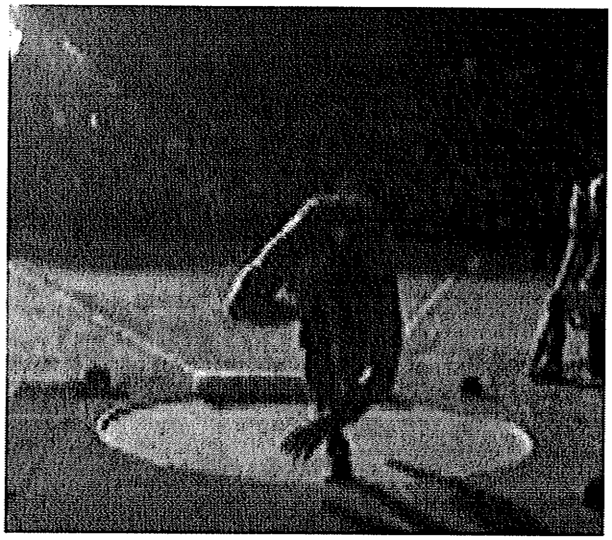


Fig. 2-13: Maximum backswing of Yuriy Bilonog at the 2004 Olympic Summer Games in Athens Greece.

There is an alternative backswing used by many of the elite glide shot putters in the world. Many shot putters load the right leg by using a more dynamic backswing. The athlete begins in a similar position to the one described above with the right hip and knee flexed along with a substantial amount of trunk flexion. However, instead of creating an isometric contraction specifically in the right quadriceps, the athletes will use the left leg to help generate a negative vertical velocity (downward velocity of the centre of gravity) to create an eccentric contraction in the right quadriceps, plantarflexors and hip extensors. In order to generate these eccentric contractions, the athlete briefly extends the right knee and hyper-extends the left hip quickly directing the left leg that is situated behind the body, upwards.

These two movements combined raise the athlete's centre of gravity which allows for a greater range of motion of the athlete's centre of gravity in the downward direction. Following this movement, the athlete flexes the left hip and left knee simultaneously as the left leg is swung quickly to a position underneath the athlete's centre of gravity and the right knee flexes. The flexion of the left knee decreases the moment of inertia about the left-right axis through the left hip helping the athlete increase the angular velocity of the hip flexion, and the swinging of the leg helps increase the ground reaction forces through the right leg. The eccentric contractions in the right quadriceps, plantarflexors and hip extensors are created as these muscles are used to control the lowering of the athlete's centre of gravity as the athlete returns to the "coiled" position prior to the force producing phase. In both backswing techniques, this "coiled" position is not held long as the athlete immediately begins the force producing phase of the skill. The shot putter's centre of gravity should be centred over the base of support of the drive leg as these movements occur (Dienart, 1978; Tellez, 1979). Throughout the backswing phase of the skill, balance is of the essence as it is very difficult to achieve a strong, well-executed glide when balance problems occur in the back of the circle (Dienart, 1978; Tellez, 1979).

Force production

Following the backswing, the athlete begins the force producing phase of the skill which consist of the drive across the circle (which is a combination of a glide stride and a delivery stride) and the delivery of the shot. The glide stride is where the athlete first pushes from the back of the circle and begins with the athlete in single-support on the right foot and ends with the athlete in the middle of the circle in a second single-support phase on the right foot once again. The path of the shot should occur in the same plane from the back of the circle to the front with no lateral deviation (Uebel, 1986). The delivery stride follows the glide stride and occurs in the front half of the circle. Here the athlete goes from the single-support phase on the right foot to a double-support phase when the left foot is planted close to the toe board (Fig. 2-14).

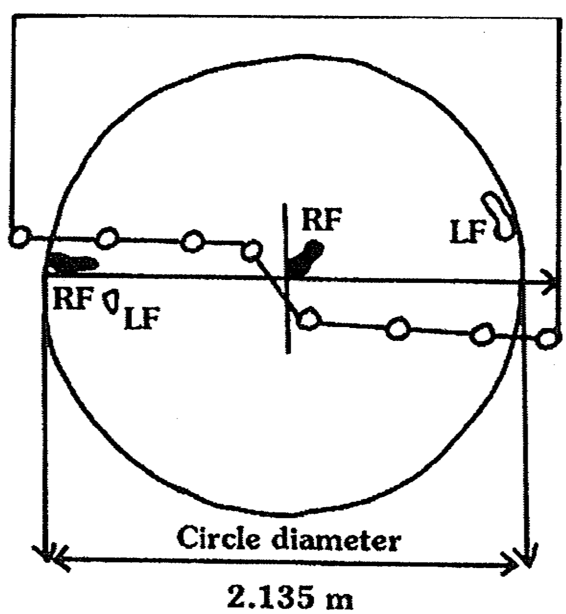


Fig. 2-14: Path of the shot across the circle during the glide technique. RF (right foot; LF (left foot). The diagonal deviation in the middle is due to the trunk rotation during the force producing phase.

The glide across the circle consists of a vigorous swing of the left leg backwards in the sagittal plane and the extension of the right leg (Fig. 2-15). More specifically, the left hip and left knee extend vigorously with the left foot remaining low to the circle as it reaches for the toe board (Holmes, 1979; Tellez, 1979). As this occurs, the right knee extends and the right ankle plantarflexes. The right hip should not extend as these movements occur. However often slight hip extension can be noticed. The athlete still wants to keep the centre of gravity as low as possible to ensure that there is the largest range of motion available for the final delivery of the shot (maximize the vertical distance that the shot moves through during the final delivery of the shot). "The purpose of the glide is primarily to give the athlete and the shot horizontal speed prior to the delivery in the front half of the circle" (Dyson, 1973). Any excessive vertical displacement of the centre of gravity during the drive to the middle of the circle is considered to be wasted energy. The greater part of the right knee extension and ankle plantarflexion is delayed until the previous left leg swing has placed the athlete's centre of gravity in a position that will allow it to be driven horizontally rather than vertically (Hay, 1993). Throughout the glide, "the left arm should hand straight down, limp and palm outwards" (Holmes, 1979).

As soon as the drive is complete, the athlete must bring the right foot immediately under their centre of gravity (Fig. 2-15). This position is achieved primarily by flexing the right knee and keeping the right foot as low to the surface of the shot circle as possible. Ideally, the foot should move in a straight path from the back of the circle towards the front of the circle and not deviate from the midline of the circle. Hay (1993) has stated that the delivery stride can be as much as 30-35 cm longer than the glide stride, but notes that many elite shot putters using this shot put technique use a glide and delivery stride of equal lengths. Bartonietz (1994) measured the distance of the glide across the circle of seven elite shot putters using the glide technique to be approximately 44% of the diameter of the circle. Whether the foot lands in the centre of the circle, or whether it is better to land in the rear-half of the circle (creating a short-long stride across the circle) is still being debated. Dyson (1973) cautions however that the glide, should never take up too much of the circle, otherwise the athlete will not have enough room for the delivery of the shot.

Typically, taller shot putters will use a short glide and longer delivery stride and smaller shot putters will be closer to equal length glide and delivery strides. The time it takes to move the foot from the back of the circle to the middle of the circle is about 0.04-0.15 seconds in elite shot putters (Hay, 1993). "The glide velocity of world class throwers ranges from [2.5m/s] to [3.0m/s] , contrasted to [13.11-13.41m/s] after the glide" (Pagani, 1981). The placement of the right foot in the middle of the circle concludes the glide stride and the delivery stride begins as the athlete begins to shift the centre of gravity from the back right foot to the front left foot (Fig. 2-15). "The glide not only serves the purpose of giving the shot initial momentum, but more importantly

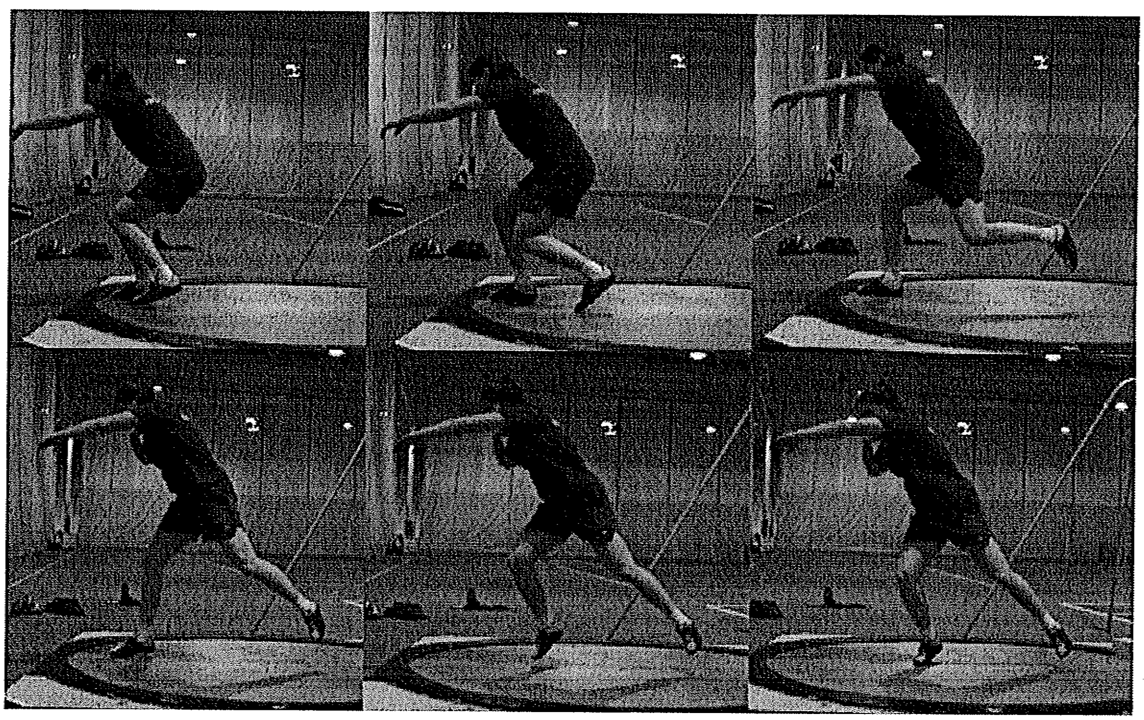


Fig. 2-15: Photo sequence of the glide across the circle.

enables the thrower to achieve a dynamic position of far greater range than can be achieved from a standing throw" (Holmes, 1979). Although the glide stride is very important to the success of the shot, "it accounts for no more than 10 percent of the total distance" (Dyson, 1973).

Following the placement of the right foot in the middle of the circle, the left foot should touch down as soon as possible and as close to the toe board as possible in order to get into the power position with minimal delay (Dyson, 1973). The closer the left foot touches down to the toe board, the greater the range of motion available for the athlete's centre of gravity to move in a horizontal direction, the greater the distance through which the shot can be accelerated and the greater the horizontal release distance of the shot. When the athlete's left foot touches down, the athlete should still be in a low position with the trunk flexed almost 90-degrees and pointing towards the back of the circle with the left hip flexed and the right knee flexed (Holmes, 1979). In Dziepak's (1998) article "Basic Glide Shot Technique" he states that when the right foot lands, the right knee should land in a position of 75-degrees of flexion. It is important to note however, that the greater amount of knee flexion that the athlete has in this position, the greater the range of motion the athlete has to forcefully extend the knee and the greater the potential angular velocity that can be achieved in this joint. Landing in a position of 90-degrees of knee flexion on the other hand would require a great deal of strength, and thus the best knee angle to have in this right knee when the right foot touches down will vary from athlete to athlete.

"The position of the upper body during the glide technique has a considerable bearing on the final result" (Hay, 1993). If the athlete does not keep the shoulders facing the back of the circle, the range of motion for the final delivery of the shot will be reduced leading to a smaller distance through which the shot can be accelerated. In addition, the more the trunk has rotated towards the front of the circle, the less the muscles of the trunk will be stretched resulting in the potential force that these muscles can exert being reduced. The hips on the other hand should be rotated 90-degrees when the left foot touches down creating a shoulder-hip separation that will help stretch the necessary trunk muscles required for the final delivery of the shot (Tellez, 1979). In other words, "upon landing in the center of the circle, the athlete must be in a torqued body position with the implement well behind the hips. The upper body is behind the hips as far back as comfort (or flexibility) will permit" (Kenneson, 1985). The greater the shoulder-hip separation, the greater the stretch will be in these trunk muscles.

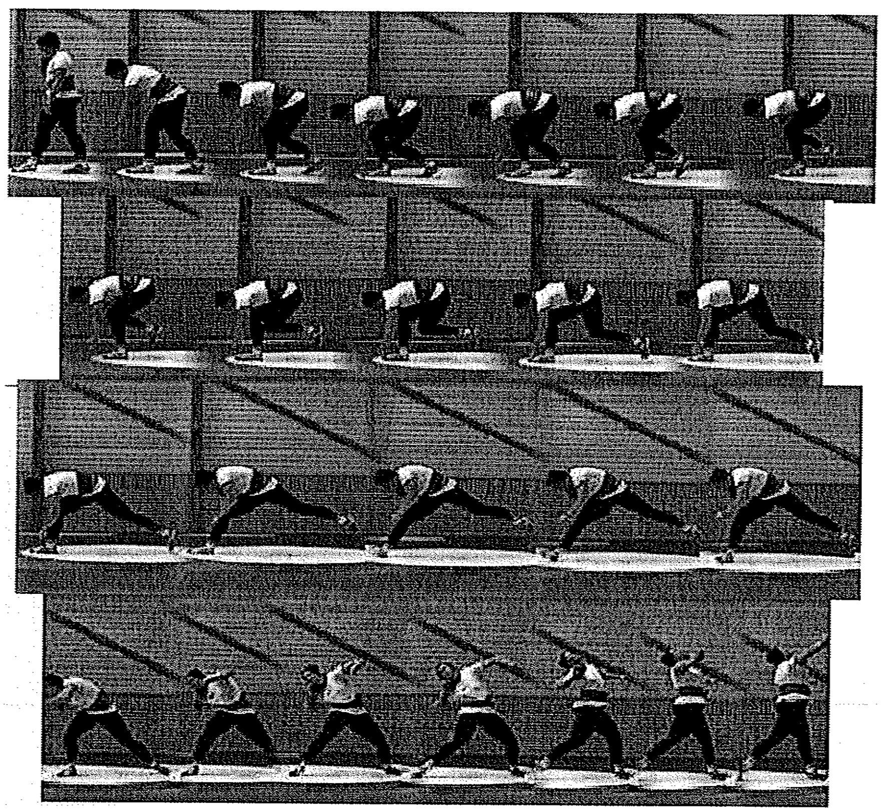


Fig. 2-16: Photo sequence of the entire glide technique from the sagittal view.

<u>Delivery and release</u>

The delivery begins with the extension of the athlete's right hip and knee along with a forceful trunk extension. In fact, the forceful trunk extension may help contribute to the generation of greater ground reaction forces through the right leg. This is seen with jumping events in which a forceful extension of the trunk has positively contributed to greater vertical velocities at take-off being reached. The extension of these joints contribute to the vertical velocity of the shot which is an important contributor to the overall horizontal distance as it determines the amount of time the shot will be in the air and can travel horizontally. Furthermore, the extension of the right leg joints contribute to the shifting of the centre of gravity forward towards the toe board which moves the shot horizontally in the intended direction of the throw. When the centre of gravity is evenly spaced between the two legs, the front left knee forcefully extends contributing to the overall vertical velocity of the shot and a higher release height.

In addition to the lifting action of the shot caused by the extension of the right leg, the upper body also rotates towards the toe board as the previously stretched trunk muscles forcefully contract. Also at this point in the skill, the left arm horizontally abducts which generates angular momentum about the shoulder axis. Tellez (1979) suggests that it is the left arm motion that leads the upper body rotation. When this left arm stops in a position of 90-degrees of shoulder flexion and 90-degrees of shoulder abduction (arm in line with the shoulders) this angular momentum is transferred to the trunk contributing to the angular velocity of the trunk about its vertical axis (Pagani, 1981).

The final movements of the delivery phase include the horizontal adduction of the right shoulder, extension of the right elbow and flexion of the wrist. As each segment decelerates, there is a transfer of momentum to the next and ultimately the momentum is transferred to the shot (Pangani, 1981). These final movements in the right arm contribute to the velocity of the shot. Elite shot putters release the shot put at an angle of 31-36-degrees (Ariel, 2004; M. Young, 2004) independent of the type of technique used. This angle is less than the optimal angle of 41 degrees predicted by physics as, "the force producing muscle/lever system of the human body may not be capable of maximum performance at this release angle" (McCoy, Gregor, Whiting, Rich & Ward 1984). Typically the shot is released from a vertical height of 220-235cm from the surface of the circle (Ariel, 2004; Coh, 2005; Luhtanen et al., 1997).

There is still debate in the shot put world regarding whether or not the athlete should be in contact with the ground or be airborne at critical instant. The advantage of being airborne at release is that it maximizes the release height (Fig. 2-17). Two shots that are released at the same velocity and same angle but one is released higher from the ground than the other, the shot that was released from a greater height (provided the angle of release was less than 45 degrees) will travel further as it will have more time to travel horizontally as

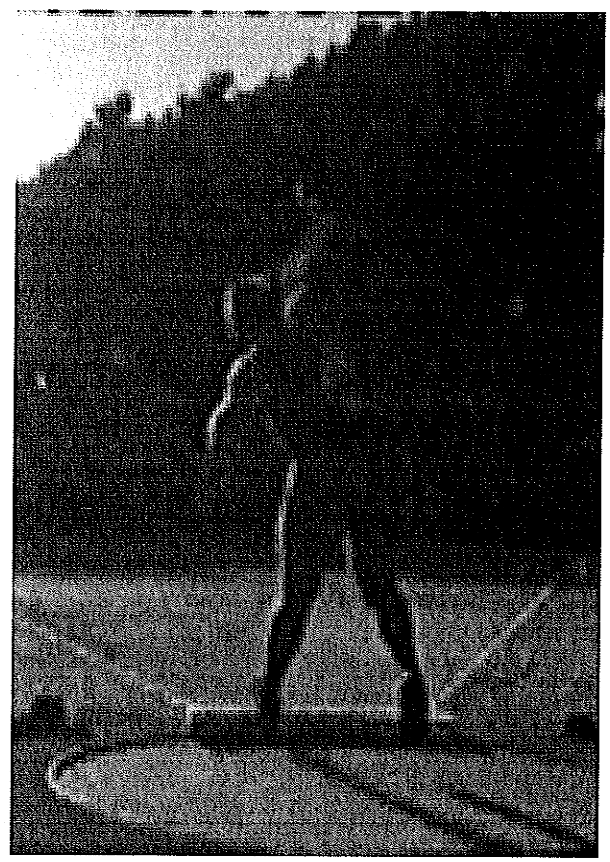


Fig. 2-17: 2004 Olympic shot put gold medalist has both feet off the ground at release.

it will have a greater total time in the air. However Pagani (1982) believes that having both feet in contact with the ground at release will produce a better release and be more efficient. "In shot putting, correct technique requires the rear foot to be firmly in contact with the ground until the arm strikes (uncoils), permitting the ground to resist the tendency of the feet to move backwards" (Dyson, 1973). On the other hand, McCoy, et al. (1984) found that world class shot putters are often airborne at release and suggest this may be a result of the explosive lifting of the body out of the power position. Whether or not it may be optimal to release the shot from an airborne position, many elite shot putters are observed to be off the ground at release (Fig. 2-17).

Follow-through

The follow-through for a glide shot putter is much more difficult than the follow-through for a rotational shot putter. After generating a great deal of horizontal momentum in the forward direction, the athlete now has to stop the forward momentum generated and try to prevent from stepping out of the circle. In order to do this, the athlete uses a reverse to try to stay within the confines of the circle. The reverse consists of bringing the right foot forward to support the athlete's weight while the left foot swings back towards the centre of the circle (Hay, 1993). "The swinging back of the left leg . . . serves to produce a contrary angular reaction that tends to move the athlete's centre of gravity back from the forward limit of the base" (Hay, 1993).

PHYSIOLOGICAL GENDER DIFFERENCES

It is true that men and women are built differently; the question is whether or not these differences affect how men and women perform the rotational shot put technique. Current research analyzing the physical differences between men and women recognize many physical and physiological differences between the genders that could have some implications for the rotational shot put technique.

Anthropometric measurements are where the most obvious differences lie. For example "a woman is on average 10-12cm smaller and some 10kg lighter than a man" (Kenntner, 1983). Keul (1983) estimates that men are on average closer to 10-15cm taller than females. The height difference alone will result in a higher release height of the shot and additional horizontal distance of the throw, provided the release velocity and the angle of release remain the same. In order to determine if the gender differences in height of Keul (1983) and Kenntner (1983) held true for the population of athletes competing in the shot put event, the author compiled the heights and weights of the top 20 males and 20 females was compiled from several internet resources – most notably, www.iaaf.com. When comparing the heights of the top 20 male and female shot putters in the world in 2006, men averaged a height of 192cm (+/-6.51cm) whereas the women had an average height of 181.4cm (+/- 6.66cm). Therefore, Kenntner and Keul's estimates of mean height differences between males and females continue to hold true for the shot putters today, 23 years later.

Males and females also differ in their average weight. Using the top shot putters in 2006 as a sample, the male shot putters had an average weight of 120.37kg (+/-12.45kg), and the female shot putters averaged 87.21kg (+/-14.99kg). This difference of over 30kg is higher than Kenntner's (1983) findings of 10kg. One reason for the large discrepancy is due to the specialized population of shot putters. The shot put event is a power and strength event so shot put competitors have heavy strength training regimes.

Physiologically, gender differences also exist in body composition, muscular architecture and strength. The muscular strength of a woman is estimated to be between

55-80% that of a man, depending on the group of muscles in question (Kenntner, 1983). More specifically, "women are about one-half (54%) as strong as men in the upper body and two-thirds (68%) as strong as men in the lower body" (Heyward, Johannes-Elis, & Romer, 1986). In other words, not only is there a difference in overall strength, but there is also a difference in distribution of strength between the two sexes and these differences may have an impact on how each gender performs the rotational shot put.

After body weight is normalized, females show statistically weaker quadriceps and hamstring muscle strength (Huston, 1996). Quadriceps strength is critical in the shot put as the legs are used to generate the majority of the vertical velocity developed on the shot as well as contributing to the horizontal velocity of the shot. "However, Hettinger established that in compensation for the lower muscular strength of women, they show some 6% greater skill than men" (Kenntner, 1983). The glide technique is a pure strength event that demands more force production out of the legs, whereas the rotational technique is more technically demanding. However women continue to use the glide technique whereas the stronger, more powerful and "less skilled" men use the rotational shot put style! The reasons for this are unclear but may be related to the lack of familiarity of females with the technique.

"Upper body strength relative to lower body strength is less in women than men" (Levine, 1984). The fact that the strength of the upper and lower body differs between the genders also suggests that the rotational technique used by males and females may differ. Women tend to have greater relative strength in their lower body which would suggest that much of their force production will come from their lower body. However this would also be the case when throwing the shot using the glide technique. The question is whether the rotational shot put technique will help maximize the force the weaker female upper body can contribute to the acceleration of the shot. The males have greater upper body strength and would most likely take advantage of this strength and alter their technique accordingly whether using the glide or the rotational technique. They may need to focus on generating a greater angular momentum in their upper body and using the rotational force to help accelerate the shot, rather than using a linear approach through the power position as is currently used by men today.

Miller, MacDougall, Tarnopolsky & Sale (1993) suggests that "the greater gender difference in upper body strength can probably be attributed to the fact that women tend to have a lower proportion of their lean tissue distributed in the upper body" (p.256). This study (based on an athletic population) does not necessarily mean that women have a smaller proportion of their weight in their upper body; it simply means that a smaller percentage of their overall lean body tissue (muscle) was found in their upper body. This finding suggests that women may need to pay particular attention to their body composition while training, and possibly focus on upper body training (bench press, barbell curls, lats pulldown etc.).

However, there is evidence that when the effects of height and lean body weight are statistically controlled for, the upper body strength of men is still significantly greater than that of women (Heyward et al., 1986). This suggests that gender differences exist in the muscle architecture. "Morphometric comparisons of male and female weightlifters and body builders have shown that women have smaller muscle cross-sectional areas that correlate with smaller fiber cross-sectional areas" (Ford, Detterline, Ho & Cao, 2000, p.1064). The cross-sectional area of muscle is very important as it is significantly correlated to strength (Miller, 1993) and studies have found that women cannot achieve the same muscle cross-sectional areas as men (Ford et al, 2000; Miller et al., 1993). Even when comparing the muscle fibres of male and female weightlifters, females continue to have smaller fiber areas (Miller et al., 1993). In other words, even women who focus on increasing their upper body strength still cannot achieve the same muscle hypertrophy as men. In terms of the rotational shot put technique, this may actually benefit women. If men have greater muscle hypertrophy, the range of motion of particular joints (such as the hips and knees) may be decreased due to soft tissue interference. Thus, women may be able to reach more advantageous positions that men cannot as they may be able to move through a larger range of motion than men. Furthermore, flexibility may be an issue as well if men do not adequately stretch out these large muscles. Greater flexibility may play an important role in the rotational shot put technique.

In 1983, Keul found that women have, approximately 2-3kg more fatty tissue than men, which is disadvantageous to skill performance as the ratio of body weight to muscle mass is lower. This 2-3kg of excessive tissue that will not contribute to generating force (as muscles do) means that there may be a higher moment of inertia about the vertical axis through the athlete as they rotate in the circle that is non-contributory. In other words, even if the female rotational shot putter decreased her moment of inertia as much as possible by maximally tucking in all of her limbs with only the distribution of her body weight causing a moment of inertia, a portion of this moment of inertia is due to excessive fatty tissue.

Another physical gender difference is the position of the centre of gravity. Women tend to have a lower centre of gravity than men which can be advantageous in terms of balance and stability. One of the factors that leads to the lower centre of gravity is the difference in the upper and lower body proportions. "...The relative seated height and the relative length of torso is greater for a woman than for a man" (Kenntner, 1983).

Whether a relatively longer torso is an advantage or a disadvantage in performing the rotational shot put is not yet known and is an interesting topic for future research.

Arm length is another anthropometric difference that may cause a difference in rotational shot put technique between the two genders. “The arms, and therefore the arm span, are relatively shorter in women than in the case of a man” (Kenntner, 1983). The difference in the relative length of the arms will add to the advantage males have over females in terms of height of release but also in the horizontal release distance, as a male shot putter can release the shot at either the same angle as a female and have a greater horizontal release distance, or release the shot at a greater angle and have the same horizontal release distance. In either case, the male athlete will throw the shot farther, with all else being equal, simply because he has the advantage of longer arms.

In terms of the shot put, Kenntner (1983) calculated that “women achieve 1% better distances than men, with lighter implements. Where there is the same velocity of the throw, the same angle of projection and only slightly lower height of the point of release, the thrusting force must be 30-40% lower because of the lighter shot” (p.95). The strength issues are important to consider when comparing the rotational shot put technique of men and women. Some positions that are beneficial to the overall performance of the males may not be advantageous for the women, due to the differences in body physique and physiological differences. Consequently, there is likely not one ideal technique for both sexes, but an ideal technique for males and an ideal technique for females that differs from the ideal male technique.

DARTFISH MOTION ANALYSIS SOFTWARE

In 1998, a company specializing in digital imaging application called InMotion Technologies Limited was founded in Lausanne Switzerland by five international business and IT specialists (www.dartfish.com, 2006). Later that year, InMotion patented a video technology called VideoFinish™ that allowed one moving object to be extracted from its background and superimposed onto another video without overlaying one background onto another. This technology ended up winning the 1999 European IST Prize – "a prestigious award granted to Europe's top IT innovators" (www.dartfish.com, 2006). The company opened up its first North American office in Atlanta, Georgia in February of 2001 and in April of that year, InMotion changed its name to Dartfish™ and VideoFinish™ earned a U.S. patent under the name SimulCam™ (www.dartfish.com, 2006). Today, Dartfish estimates that over 10,000 people in the world use Dartfish and Dartfish's SimulCam™ technology which is used by broadcasting companies such as CBC, NBC, ABC and Fox. It has been used for major international events such as the World Athletics Championships and the Olympic Games (www.dartfish.com, 2006). Victor Bergonzoli, president of Dartfish USA, estimates that "Dartfish is used by 90 percent of the Olympic athletes" (www.dartfish.com, 2006). According to Ron Imbriale, Dartfish's vice-president of sales, "77 of the 103 U.S. Olympic medal winners at the Athens Games used Dartfish's products extensively" (www.dartfish.com, 2006).

SimulCam™ is only one of the features provided by Dartfish that was used for the shot put analysis in this study. Dartfish gives the athlete, coach or researcher, "the capability to simultaneously view multiple videos, overlay action sequences, and . . . can also be used to gather and store quantitative information about athlete testing sessions, comparing body positions and techniques and how they are related to performance

(Stergiou, 2006). The features of Dartfish TeamPro 4.0.7 that was used in this study are found in the Analyzer mode which includes various drawing tools such as circles, squares, markers, curved lines and gridlines. The more advanced analyzer tools that were used for the majority of the quantitative analysis are the measurement tool, angle tool, data table and tracking tool.

Dartfish's measurement tool was used to calculate distances such as release height and step length by automatically converting the distances drawn on the computer screen into actual distances. In order to convert all drawings on the video into actual distances, Dartfish uses the known distance of an object in the video and divides this number by the measured length of the object on the video (real/image) and calculates a conversion factor. For all additional measurements made on the screen, Dartfish automatically multiplies the measured distance on the screen by the conversion factor and computes the actual distance which is displayed on the screen. For the purpose of this study, the diameter of the shot circle was used as the reference object (object of known length in the screen). Once an object is set as a reference for measurement, the data table can be used to calculate linear and angular velocities. Dartfish uses the frame counter and converts the frames to actual time and uses the distance/angle drawn in the screen and the appropriate formula to calculate the velocity. Dartfish's data table can also calculate acceleration by taking the calculated velocities and dividing them by the specified time interval over which the changes in velocity occurred. The angle tool was used for all joint measurements and the release angle of the shot. Dartfish automatically measures the angle drawn on the screen without the researcher requiring a protractor. The tracking tool allows for an object in the video to be tracked automatically with the option to display the path of the object throughout the movement. When the tracking tool is used in conjunction with the data table, average velocities and accelerations of the object can be automatically calculated and the data table can later be exported into another program such as Microsoft Excel for further analysis if required.

In addition to these tools, Dartfish can be used for frame by frame playback with video management tools that allows up to four videos to be played at once and synchronized using Dartfish's Timeline. For precise angles and measurements to be taken, all videos can be zoomed in and magnified. Furthermore, Dartfish has a frame counter that displays the time on the film and is accurate to 0.017 seconds. Finally, all drawings and measurements created on the video(s) was automatically saved with the video. By using the Snapshot tool or Picture tool all the drawings with the video(s) on the screen was saved as a picture in the form of a JPEG or Bitmap file. All the Dartfish tools that was utilized for this study are summarized in Table 2-1.

Table 2-1: Summary of the Dartfish analysis tools that will be used for the study

Angle Tool	Enables the researcher to measure joint angles.
Data Table	Enables the researcher to collect time-dependent data. (This tool with be used to calculate velocities for this study)
Drawing Tools	Different shapes and lines can be drawn to highlight points of interest or reference.
Distance Tool	As long as there is an object of known length in the video, the distance tool automatically calibrates the video for any other measurements that need to be made.
Frame in Frame Tool	Allows a desired selected portion of the video frame to be zoomed in while the rest of the video frame remains the same.
SimulCam ™	Superimposes one athlete over another without the interference of the background.

CHAPTER III
METHODS

SUBJECTS

Twenty rotational shot putters ranging in age from 19 and 39 years old participated in this study. Ten male subjects were recruited from the 2006 Division II Outdoor Track and Field Championships in Emporia, Kansas and all had thrown further than 15.90m which was the provisional requirement for males to compete in this event. Five of the eight female participants in this study were also NCAA Division II athletes and had thrown a minimum distance of 13.26m to qualify for the NCAA Division II National Championship. Two female participants were current Canadian university athletes and one female was a former Canadian national team shot putter who continues to throw the shot. Two additional male shot putters were recruited from the University of Alberta in order to capture a transverse view of the male rotational shot put technique.

Permission was granted by the NCAA Division II Championship committee to recruit subjects for this study on site at the NCAA Division II championships' "Open circle" practice. "Open circle" means that the shot circle was open to anyone who wanted to use the throwing circle to throw shot put. Arrangements were also made through the head coach of the University of Alberta to film her and her athletes for the study. All of the participants filled out an informed consent form and all video was captured and analyzed using Dartfish 4.0.7 Software.

FILMING TECHNIQUE

Filming took place in Emporia Kansas, at Zola Witten Track in Fran Welch Stadium at the 2006 NCAA Division II Outdoor Track and Field championships in May

2006, and during a training session at the University of Alberta's Foote Field in Edmonton Alberta.

At Welch Stadium, two Canon GL2 Digital Camcorders with built-in image stabilizers were used. One Canon GL2 camera was set up approximately 5m away to the right of the shot put circle (left of the circle from the frontal view) at a 90 degree angle to the midline of the throwing sector to capture the final power position, delivery and release of the right handed athletes from the sagittal plane (Fig, 3-1). The second Canon GL2 camera was set up 5m behind the shot put circle aligned with the midline of the throwing sector and shot put circle. This camera captured the posterior view of the circle which was used primarily to measure the width of the base of support during the first double support phase, and various joint angles and the position of the shot throughout the skill.

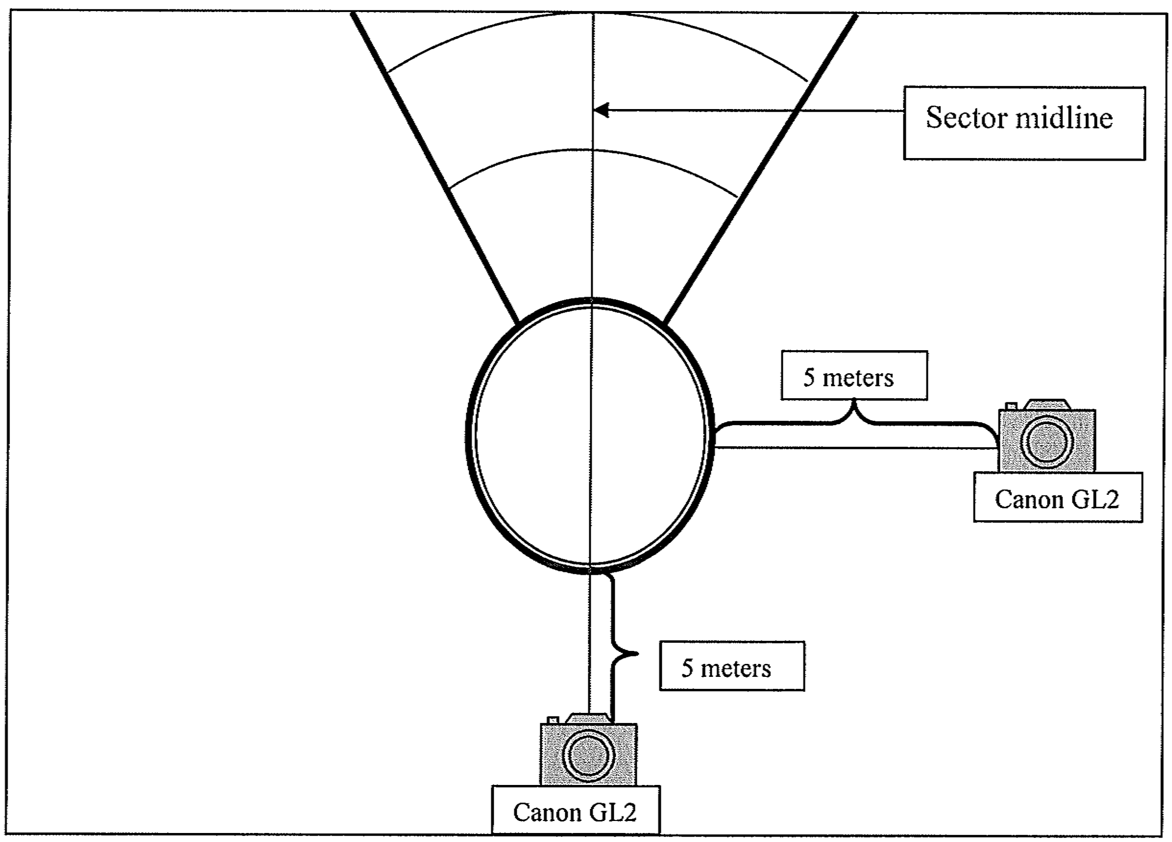


Fig. 3-1: Overhead view of camera setup at Fran Welch Stadium, Emporia Kansas

Both cameras were secured onto tripods to prevent any unwanted camera movement. Due to the bright filming conditions, both cameras were able to be set to a shutter speed of 1/8000 of a second which successfully prevented any blurring from occurring on the captured videos. Following the camera set up, each camera recorded the circle without any participants in the view to optimize the quality of Dartfish's SimulCam mode that was used to make comparisons between athletes.

The camera setup at Foote Field was similar to the one used at Fran Welch Stadium, with Canon ZR70 and Canon Optura200MC cameras used in place of the Canon GL2 cameras. An overhead camera apparatus (Fig. 3-2) was also set up over the shot circle so a third camera could capture a transverse view of the skill. The overhead camera, a Canon ZR700 with a built-in image stabilizer and a wide angle lens, was situated approximately 5m above the surface of the throwing circle. A shutter speed of 1/1000 of a second was used on all three of the Canon cameras to eliminate motion blur.

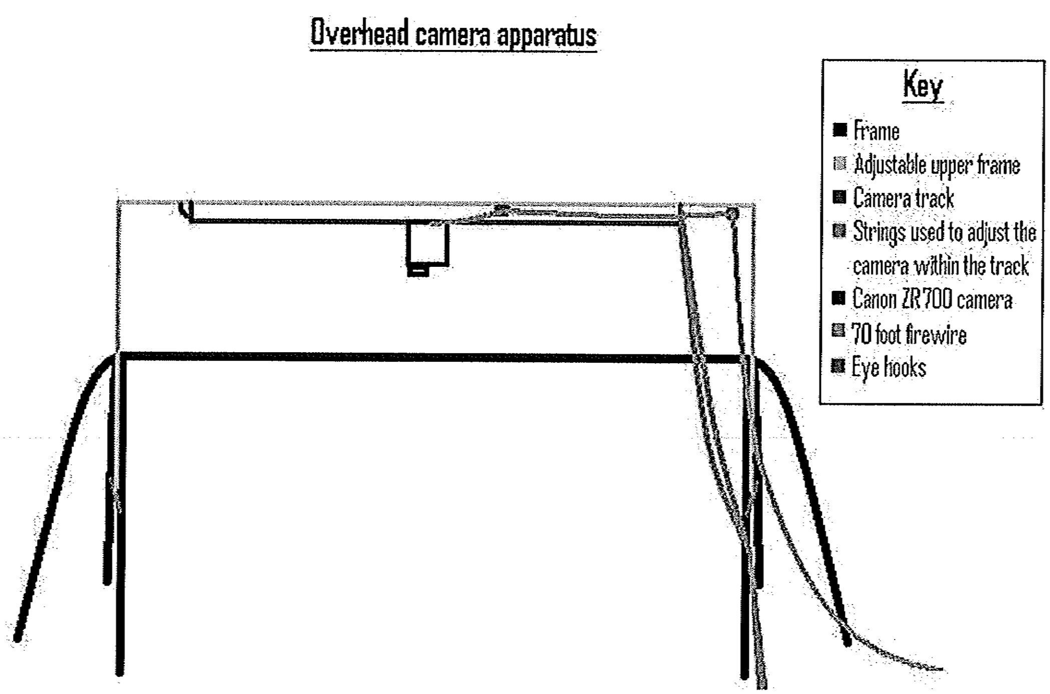


Fig. 3-2: Overhead camera apparatus.

The ZR700 was connected to a Toshiba Satellite JM8 laptop computer via a 70 foot 4 pin to 4 pin firewire. Using "In the Action" mode from Dartfish, the transverse view captured by the ZR700 was viewed live on the computer screen to ensure that the camera view was correct and included the whole skill. The video filmed using the overhead camera was used to measure the angular velocity of each turn and to determine the angular velocity of the shot through each stage of the rotational shot put skill. The overhead camera frame did not interfere with the sagittal view taken from the cameras on each side of the shot circle. Refer to Fig. 3-3 for the camera setup at Foote Field.

From these three camera views (posterior, sagittal and transverse view for each throw), all major joint angles and velocities were measured using the Analyzer mode available in the Dartfish Team Pro 4.0.7 software program.

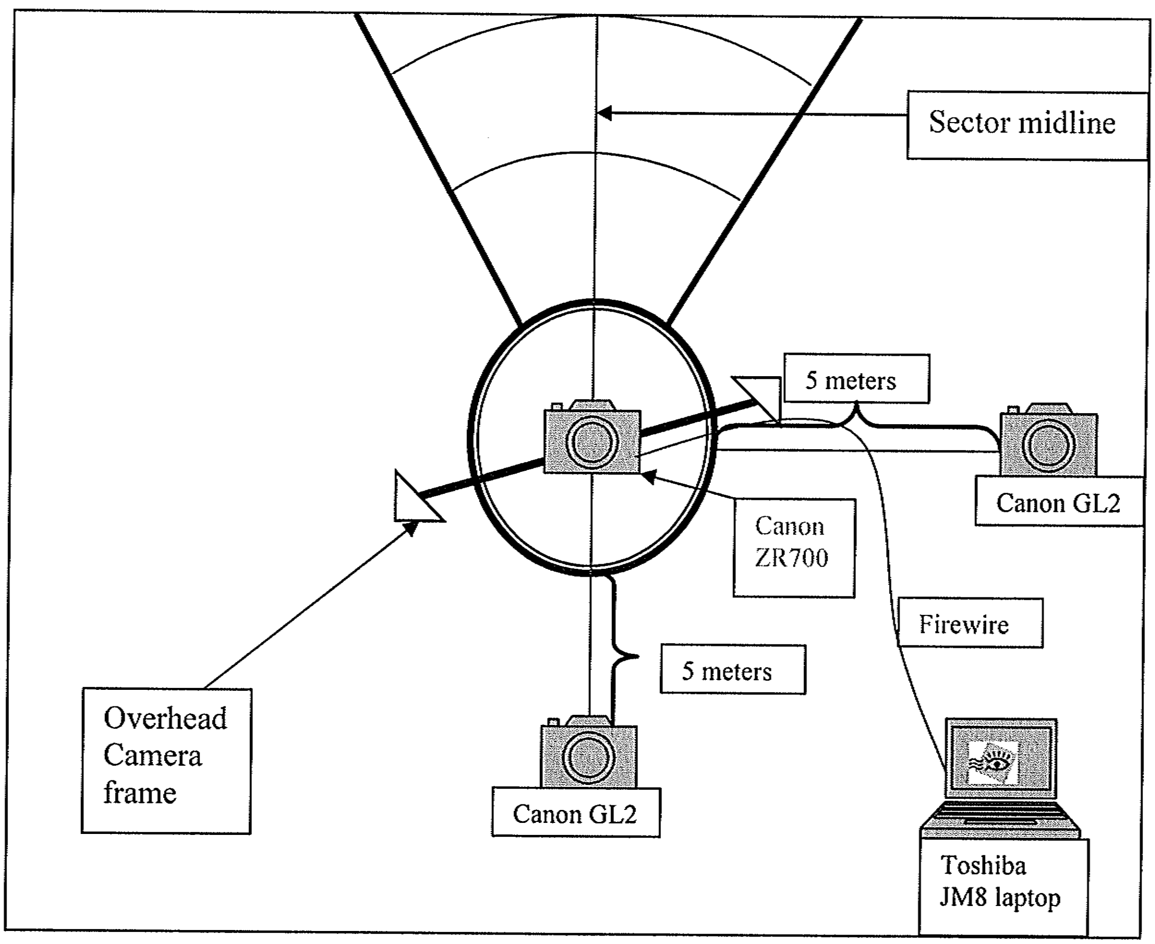


Fig. 3-3: Overhead view of the camera setup at Foote Field, Edmonton Alberta.

Overhead camera

Angular velocity of the hips, shoulders and shot throughout the rotational shot put skill is an important contributor to the success of each throw. In order to quantify the angular velocities of each turn and the angular velocity of the shot it is vital that an overhead camera is used. Aside from the study by Coh and Stuhec (2005), there is very limited published research using an overhead camera and the data that were collected for this study (using an overhead camera) at the University of Alberta will be valuable to not only other athletes and coaches, but to other researchers in the field.

Filming Protocol

All athletes participating in the study completed informed consent forms and permission was granted from each of the athletes' coaches for the athletes to participate in the study. In addition, each athlete filled out a form which included personal information such as height, weight and their personal best (PB) throw distances.

The athletes were given instruction only by their coaches during the practice session and there was no interference by the researcher. It is likely that any instructions given to an athlete by their own coach will only help improve the technique and help ensure that the athlete produces a satisfactory throw. Each athlete threw a minimum of six complete throws following their own individualized warm-up. The throwing order was decided amongst the athletes and coaches just as they would during any other training session before competition. During the practice session, all the athletes (males and females) shared the circle at the same time; hence, each athlete had adequate rest between throws – similar to the rest each would receive in a competitive situation. A marker was used to mark the distance of each throw and the athlete's name and throw number were written on each marker immediately following each throw. In the interest of time and in not interfering with the practice sessions, all the throws were measured following each practice session and recorded on a chart which included the athlete's name, throw attempt number and distance of each attempt in meters. All of the subjects were provided with a compact disc containing all of their recorded throws, the day following filming.

Dartfish does not require the cameras to have the same zoom factor in order to calculate the necessary variables for this study. Therefore, there was no concern that filming in different locations at different times might produce different results.

DIGITAL VIDEO ANALYSIS

The footage obtained from all of the cameras was imported into the Toshiba Satellite JM8 laptop computer using Dartfish's "In the Action" feature. A preliminary video analysis was used to ensure that there were no obstructions in the camera views. The longest throw was considered each athlete's best throw and used for analysis provided the camera views are unobstructed. All remaining video was stored on a 300GB Maxtor external hard drive until the completion of the study.

Although only one throw of each athlete was analyzed, the top two throws of each athlete were downloaded and analyzed side by side using Dartfish's split screen mode to ensure that the best throw technique was chosen. Dartfish's "Analyzer" mode allows for all three views to be synchronized and viewed simultaneously using Dartfish's "Timeline" and "Split screen mode" then viewed frame by frame for analysis. The selected video clips were imported into Dartfish's "Analyzer" mode and set up in a Storyboard where qualitative and quantitative comparisons of the technique of each athlete were made.

The angle drawing tool, distance tool and data table were used for all quantitative analyses. The drawing tools available in Dartfish's analyzer mode were used for qualitative analysis as well. All critical joint angles were measured, in addition to angular and linear velocities, angle of release, and the distance the shot was released in relation to the toe board. Differences in technique were also observed using the Simulcam feature of Dartfish. Simulcam allows for two video clips to be placed on top of each other and then synchronized at a particular point of interest. Thus, temporal differences could be observed in addition to minor technique differences and the time that each difference occurred, and are accurate to the thousandth of a second. Pictures of importance were taken using the Dartfish Clipboard feature and were cleaned up using the Adobe Photoshop Elements II program to produce the sharpest, clearest picture possible and were included in the results and discussion section of this study.

Variables calculated and analyzed

The key variables that were analyzed were taken from the beginning of force production to the final velocity of the released shot. Video analysis was used to measure the resultant shot velocity with the calculated vertical and horizontal components, angular velocity of the back knee extension (left or right knee depending on whether the athlete is right or left handed), hip and trunk extension angular velocities, the angular velocity of the wrist flexion, elbow extension and horizontal shoulder abduction of the throwing arm, along with the height of release and angle of release. In addition, the angular velocity of the hips and trunk rotation about the athletes' longitudinal axis was calculated and compared for each gender. All the variables that were calculated is included in Tables 3-1 and 3-2.

Table 3-1: List of all variables that were calculated at maximum backswing and the first turn.

Phase of the skill	Variables measured
Maximum backswing	▪ Width of base of support ▪ Left knee flexion ▪ Trunk flexion ▪ Left hip flexion ▪ Relative height of the shot's centre of gravity ▪ Left shoulder flexion
First turn	▪ First turn average angular velocity of the hips ▪ First turn average angular velocity of the shoulders ▪ Shoulder-hip separation (SSS) ▪ First turn angular velocity of the shot ▪ Horizontal linear velocity of the shot through the first turn ▪ Right shoulder abduction ▪ Right hip abduction during leg sweep ▪ Lateral trunk flexion during leg sweep (to the right) ▪ Length of "step" into the centre of the circle ▪ Height of shot's centre of gravity at single support ▪ Height of shot's centre of gravity at take-off ▪ Height of shot's centre of gravity at peak height of airborne phase ▪ Right hip extension at single-support ▪ Extension of left knee at take-off ▪ Right hip abduction during leg sweep ▪ Lateral trunk flexion at leg sweep ▪ Left knee flexion at single support ▪ Angle formed between the line from the left toe and left hip with the vertical (lean into the circle) during the right leg sweep

Table 3-2: List of all variables that were calculated during the second turn and release.

Phase of the skill	Variable(s) measured
Second turn	▪ Second turn angular velocity of the shot ▪ Horizontal linear velocity of the shot through the power position ▪ Horizontal linear velocity of the shot through the second turn ▪ Shoulder-hip separation (SDS) ▪ Right shoulder flexion at max. right knee during single-support ▪ Trunk flexion at maximum right knee flexion during 2nd single-support ▪ Maximal right hip flexion during second turn ▪ Lateral trunk flexion at power position ▪ Maximum right knee flexion during second turn ▪ Width of base of support at 2nd double support ▪ Relative height of shot's centre of gravity at 2nd single support ▪ Relative height of shot's centre of gravity at the beginning of double support ▪ Right knee flexion at right foot touch down ▪ Trunk flexion at right foot touchdown ▪ Left shoulder flexion at right foot touch down ▪ Right knee angle at power position
Release	▪ Horizontal release distance ▪ Distance of left toe from toe board ▪ Right knee angular velocity during force production ▪ Release height ▪ Release angle ▪ Release velocity

Variables Measured

Using the 180-degree system, all joint angles were measured using the Dartfish Team Pro 4.0.7 Analyzer angle tool. In anatomical position, according to the 180-degree system for measuring joint angles, all joints are in a position of zero degrees and any deviation from anatomical position is measured (Fig. 3-4). Hyperextension is used when describing motion in a posterior direction from the starting anatomical position. Knee flexion, hip abduction, hip flexion, shoulder flexion, shoulder abduction and elbow flexion were calculated at the times of interest (final power position and critical instant). Shoulder and hip rotation were calculated and recorded. A line going from the left acromion process to the right acromion process was drawn to represent the line of the shoulders and a line from the left anterior-superior iliac spine (ASIS) to the right anterior-superior iliac spine was drawn to represent the line of the hips (Fig. 3-5). These lines

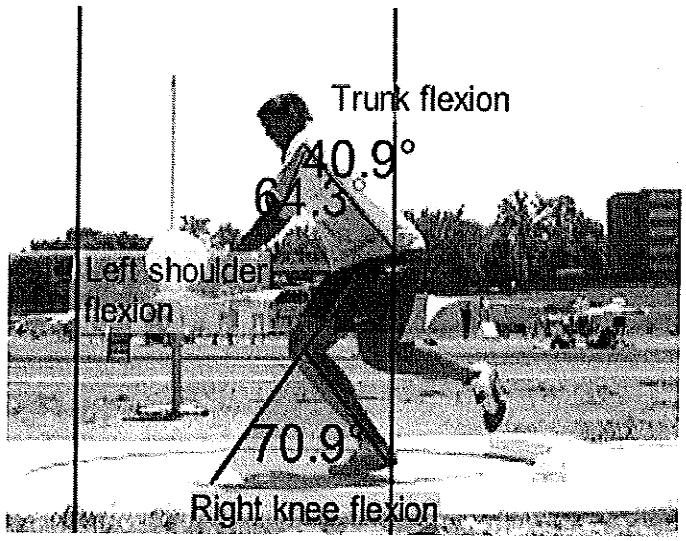


Fig. 3-4: 180 degree system measurement of trunk flexion, left shoulder flexion and right knee flexion.

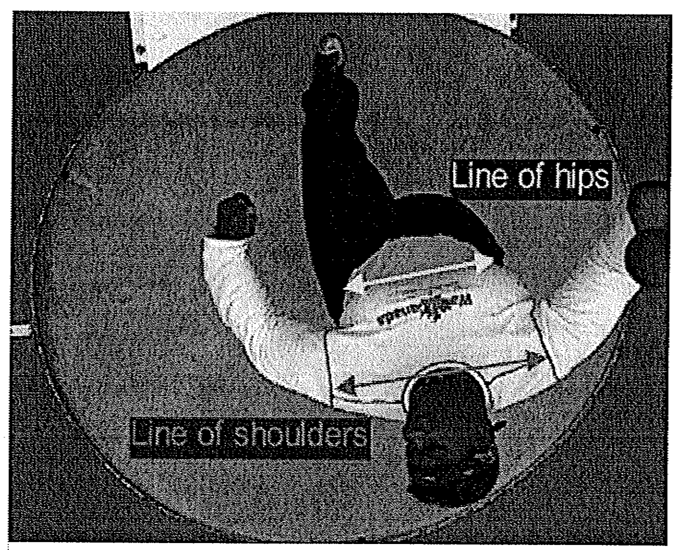


Fig. 3-5: Example of the line drawn to represent the line of the shoulders and hips.

were used to measure the shoulder-hip separation throughout the skill and to help calculate the rotational velocity for the shoulder girdle and the pelvic girdle. A transverse overhead view was captured for 5 athletes (2 males and 3 females) that participated in the study. From this view, 10 additional variables were measured which included angular velocities and measurements of shoulder-hip separation at key phases in the skill. An adjusted angular velocity was calculated for the shoulders and hips at release and measured to the point where release should have occurred when each of these segments should be parallel with the toe board. This variable was labeled "RELh" and was used to factor out technique error.

The shoulder-hip separation is the measured angular difference between the line of the hips (the line drawn from one anterior superior iliac spine to the other) and the line of the shoulders (from one acromion process to the other) (Fig. 3-6). A positive shoulder-hip separation indicates the hips are leading the shoulders in the rotation which is desirable at the second single-support phase of the skill.

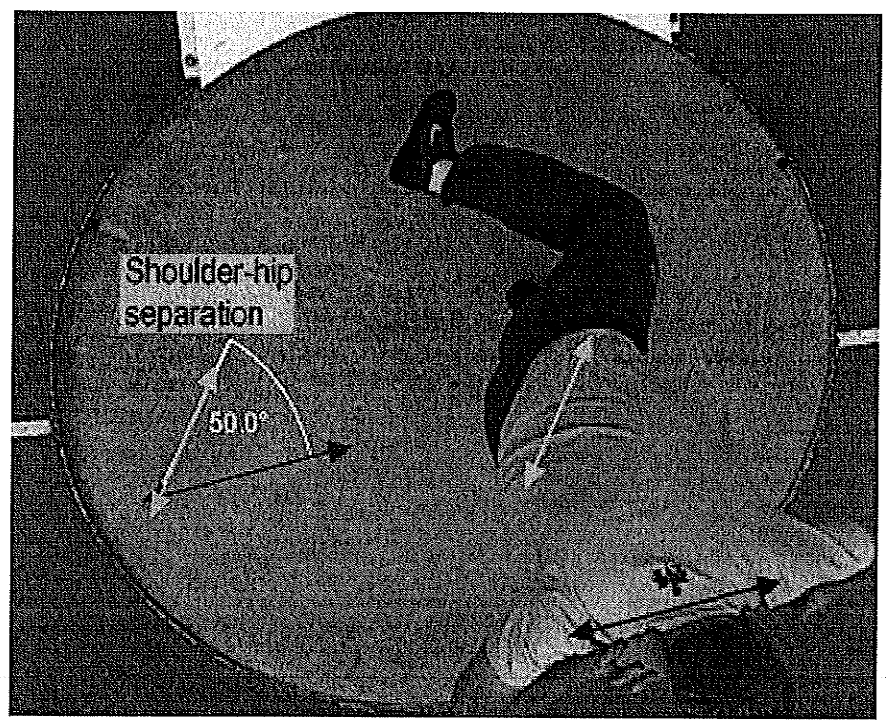


Fig. 3-6: Measurement of shoulder-hip separation.

STATISTICAL ANALYSIS

A reliability test was conducted to assess the consistency and precision of measurements taken from film data of the subjects using Dartfish by the experimenter. Ten variables were chosen for the test consisting of a combination of angles, distances and velocities. All 10 variables were measured on a single subject and each variable was measured on 15 different occasions with a minimum of 7 days between each trial. The reliability testing was conducted over a fifteen week period from May 14th, 2006 to August 24th, 2006. The measurements from each trial were recorded on separate Excel spreadsheets so the results from each week were not visible to the experimenter. At the conclusion of the data collection, all of the results from each week were compiled into a master table and the results were statistically analyzed. The coefficient of variance was used to determine the precision of the experimenter and was calculated using the StatView 4 statistics program for each of the 10 variables measured. The coefficient of variance is a measurement of how close repeated trials are to one another and is calculated by dividing the standard deviation for the sample by the sample mean producing a score that represents the percentage of error in the measurements. The lower the coefficient of variance, the higher the precision is of the experimenter.

The selection of the independent variables was based on previous research studies that analyzed the rotational shot put technique. The dependent variable for this study was throw distance. All means and standard deviations for all the variables for male and female groups were calculated using the Microsoft Excel software program and then multiple T-tests were conducted to determine significant differences between the genders. A p-value (or a type I error) of 0.10 was used to indicate statistical significance of differences between the two groups. This study is the first known to compare females and males using the rotational shot put technique. Committing a type 1 error and finding differences between the two groups when there actually is no true difference, was considered more acceptable for an exploratory study such as this one, than missing differences. Next, a Pearson's correlation analysis was conducted to examine the relationship between each independent variable and throw distance.

Finally, a forward stepwise multiple-regression analysis was used to eliminate parameters from the regression equation that were found not to be significant predictors of the measured throw distance. All 40 variables were entered into the regression analysis. The variable that explains the most variation in throw distance is the variable that is entered into the regression equation first. The variable that is entered in this "first step" is the variable that has the highest and most significant correlation to throw distance. The remaining independent variables that were not included in the equation during the first "step" were then regressed on throw distance jointly with the first variable entered. In other words, all the remaining variables are then correlated to throw distance and the first variable entered, and the variable that explained the most remaining variation (had the highest and most significant correlation) was then added to the equation in the second step. This process continued until as much variation as possible in throw distance was accounted for by the resulting regression equation.

The forward stepwise multiple-regression analysis provided a list of the most important kinematic variables that predict throw distance and ranked them in order beginning with the variable of most importance. A separate forward stepwise multiple-regression analysis was conducted for the males and females. If the ranked list of the important kinematic variables of the males and females differed in anyway, this may suggest that the rotational shot put technique used by females is different than the rotational shot put technique used by males. The forward-stepwise regression tests for interrelationships between independent variables and eliminates them accordingly. Two previous shot put studies (Alexander, 1996; M. Young, Li, L., 2005) used similar procedures for their studies.

CHAPTER IV
RESULTS

This chapter will report the findings of the statistical analysis and highlight the key differences found between the rotational technique used by males and the rotational technique used by females. Furthermore, the statistical analysis may provide insight into the optimal rotational shot put technique of males and females. The height and weight of the participants in this study are provided in Table 4-1 below.

Table 4-1: Description of subjects.

	MALES N=10		**FEMALES N=8**	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**
Body Mass (kilograms)	*131.59±15.76*	*109.99-159.09*	*91.99±8.83*	*79.55-105.00*
Height (meters)	*1.89 ± 5.80*	*1.83-2.03*	*1.69±0.07*	*1.55-1.78*
Throw distance (meters)	*16.92±0.44*	*16.16-17.40*	*13.90±0.68*	*13.03-15.12*

RELIABILITY TEST

Based on the coefficient of variance for all 10 variables measured, not one of the variables has a coefficient of variance higher than 0.039, thus, there is no significant variance in the measurement of any variable from trial to trial and the measurements are considered to be very precise. The results of the reliability test are found in Table 4-2.

Table 4-2: Statistical breakdown of the reliability test data.

Variable	Mean	S.D	Minimum	Maximum	Range	Coefficient of variance
Trunk flexion at MBS	26.60	0.80	25.80	28.50	2.70	0.030
Right hip abduction at LS	31.20	1.20	29.40	33.20	3.80	0.039
Length of first "step"	1.16	0.01	1.14	1.17	0.03	0.010
Height of shot's centre of gravity at SSS	1.30	0.01	1.29	1.31	0.02	0.010
Maximum right knee flexion during second turn	74.50	0.90	73.40	76.90	3.50	0.012
Lateral trunk flexion in PP	14.40	0.20	14.00	14.70	0.70	0.017
Release velocity	7.92	0.14	7.67	8.10	0.43	0.020
Release angle	35.10	0.60	33.90	36.00	2.10	0.017
Release height	1.92	0.01	1.91	1.93	0.02	0.037
Horizontal release distance	6.20	0.20	5.80	6.40	0.60	0.032

NOTE: S.D. = standard deviation; MBS = maximum backswing; LS = leg sweep; SSS = second single support; PP = power position.

COMPARISON OF MEANS FOR MALES AND FEMALES FOR EACH PHASE

Phase 1: Maximum Backswing

In the maximum backswing phase of the skill, 6 variables were measured. The variables in addition to the means and standard deviations for both male and female rotational shot putters are shown in table 4-3. Based on an alpha level of 0.10, there were no significant differences between the two genders for any of the measured variables.

Table 4-3: Measured variables and comparison of the maximum backswing phase of the rotational shot put.

Variable	Males N=10		Females N=8		T-value	P-value
	Mean	**SD**	**Mean**	**SD**		
Width of base of support @ first double support (cm)	70.62	12.63	73.12	8.57	1.34	0.31
Trunk flexion (deg)	31.92	13.19	25.48	8.79	-1.24	0.12
Left hip flexion (deg)	47.50	18.60	43.40	26.91	-0.37	0.36
Left knee flexion (deg)	57.11	21.64	70.51	26.53	1.15	0.13
Relative height of shot's centre of gravity	71.21	5.27	73.98	3.83	1.29	0.11
Left shoulder flexion (deg)	99.57	1.41	95.93	22.10	-0.41	0.35

Phase 2: First Turn

Comparison of the means of the measured variables in the first turn, are presented in Table 4-4. The variables that proved to be different for males and females include: The relative height of the shot's centre of gravity and the length of "step" across the circle (Table 4-4). The calculated mean for the relative height of the shot's centre of gravity for the male shot putters was 0.74 whereas the females had a mean of 0.78 (Fig. 4-1). In other words, at the peak of their backswing, females held the shot at 78% of their standing height as compared to the males who held the shot at 74% of their standing height. This equals a mean difference of 0.04 which was significant at a p-value of <0.05 (Table 4-4).

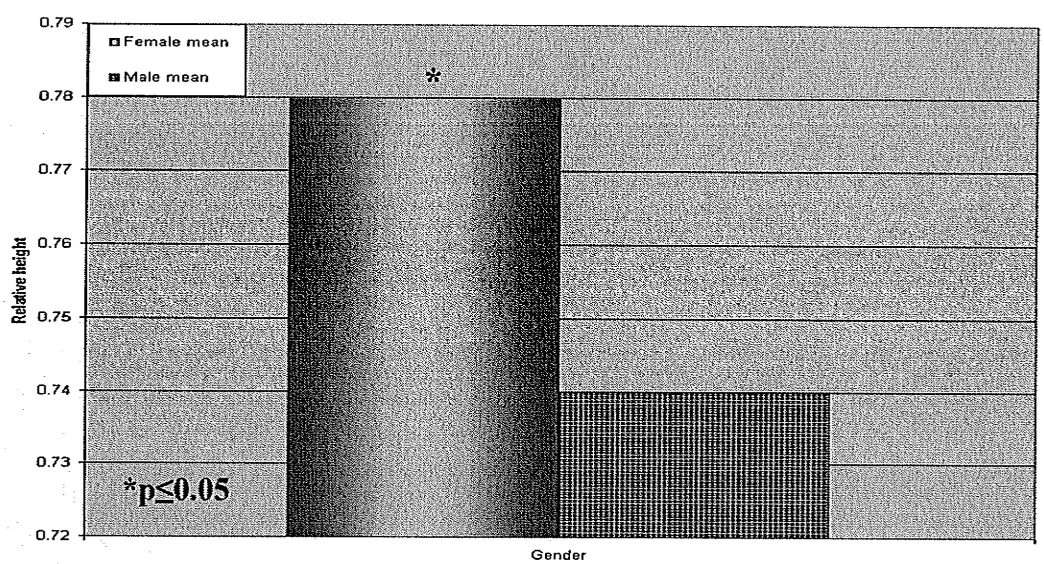


Fig. 4-1: Comparison of the relative height of the shot's centre of gravity at first single support.

Differences in other variables such as knee flexion angles and hip and shoulder abduction angles were not significant between the groups. A large amount of variance was found in both groups making it difficult to isolate any statistically significant differences amongst the males and females.

Table 4-4: Measured variables and comparison from the first turn (FSS-SSS).

Variable	Males N=10		Females N=8		T-value	P-value
	Mean	SD	Mean	SD		
Avg. horizontal linear velocity of the shot through the first turn (m/s)	0.60	0.13	0.68	0.29	-0.69	0.25
Right shoulder abduction at FSS (deg)	79.42	10.58	78.35	13.36	0.18	0.43
Left knee flexion at FSS (deg)	64.37	10.51	57.61	18.30	0.93	0.19
Relative height of shot's centre of gravity at FSS	0.74	0.05	0.78	0.04	-1.88	0.04*
Right hip flexion at LS (deg)	19.98	19.56	12.74	15.98	0.86	0.20
Right hip abduction during LS (deg)	29.17	11.87	31.09	11.43	-0.35	0.37
Angle of trunk to the right of vertical at LS (deg)	-8.86	10.92	-2.09	10.97	-1.30	0.11
Lean into circle at LS (deg)	20.98	5.17	22.23	5.07	-0.51	0.31
Left knee flexion at TO (deg)	26.28	9.99	20.04	10.27	1.30	0.11
Relative height of shot's centre of gravity at TO	0.80	0.03	0.80	0.04	0.05	0.48
Relative height of shot's centre of gravity at PA	0.79	0.03	0.80	0.04	0.36	0.36
Relative length of "step" across the circle (cm)	0.60	0.06	0.62	0.08	-0.49	0.32

$*p \leq 0.05$

NOTE: FSS = first single support; LS = leg sweep; TO = take-off; PA = peak height during airborne phase.

Phase 3: Second Turn

A summary of the means and standard deviations of the measured variables for the second turn are shown in Table 4-5. The majority of the technique differences found between the male and female rotational shot putters occurred during the second turn as 7 variables produced significant differences. Females had greater flexion angles in 3 of the 4 measured angles during the second turn (Fig. 4-2).

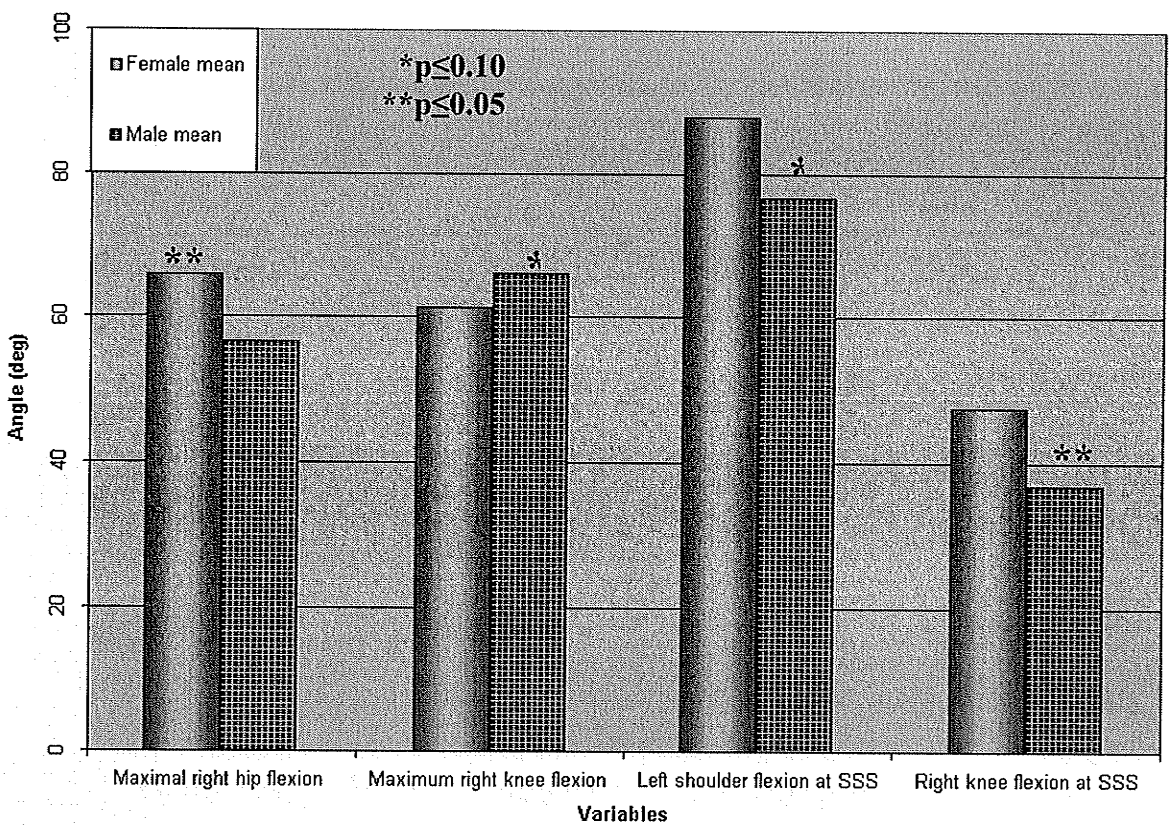


Fig. 4-2: Comparison of measured angles in the second turn including: Maximal right hip flexion; maximum right knee flexion; left shoulder flexion at SSS; right knee flexion at SSS.

Females were found to have reached greater maximal right hip flexion during the second turn, and a greater right knee flexion angle measured at SSS (Fig. 4-2). Both variables were found to be significantly different between males and females at $p \leq 0.05$.

Table 4-5: Comparison of second turn variables for males and females.

Variable	Males N=10		Females N=8		T- value	P- value
	Mean	SD	Mean	SD		
Left shoulder flexion at SSS (deg)	76.66	17.87	87.86	16.35	-1.39	0.09**
Trunk flexion at SSS (deg)	31.06	7.46	30.59	7.62	0.13	0.45
Right knee flexion at SSS (deg)	36.72	13.34	47.48	5.48	-2.32	0.02*
Relative height of shot's centre of gravity at SSS	0.77	0.03	0.71	0.05	-1.07	0.15
Trunk flexion at maximum right knee flexion during SSS (deg)	34.21	4.60	34.19	7.92	0.01	0.50
Right shoulder abduction at max. right knee during SSS (deg)	78.83	15.32	79.85	15.12	-0.14	0.44
Second turn average linear velocity of the shot (SSS-SDS) (m/s)	1.19	0.35	1.10	0.34	0.52	0.31
Relative width of base of support at SDS (cm)	0.33	0.07	0.34	0.06	-0.28	0.39
Relative height of shot's centre of gravity at the beginning SDS	0.68	0.03	0.71	0.05	-1.59	0.07**
Lateral trunk flexion at PP (deg)	22.57	7.85	22.01	4.60	0.19	0.43
Maximal right hip flexion during second turn (deg)	56.64	11.13	65.95	11.36	-1.74	0.05*
Maximum right knee flexion during second turn (deg)	66.07	5.81	61.29	7.95	1.42	0.09**
Average linear velocity of the shot through PP (m/s)	5.71	0.56	6.29	1.08	-1.37	0.10**
Right knee angle at PP (deg)	56.38	8.98	56.80	9.42	-0.10	0.46
Angular velocity of the knee during force production	397.31	81.24	317.34	75.69	2.16	0.02*

***p≤0.05**
****p≤0.10**

NOTE: SSS = second single support; SDS = second double support; PP = power position.

The difference in the maximal hip angle during the second turn was 9.31 degrees and the difference in the right knee flexion at SSS was 10.76 degrees.

The female rotational shot putters had a mean maximum right knee flexion angle of 61.29 degrees (±7.95 degrees) whereas the males had a mean of 66.07 degrees (±5.81 degrees). The left shoulder flexion angle for males and females were also found to be significantly different to a p-value of <0.10 (76.66±17.87 degrees vs. 87.86±16.35 degrees) (Table 4-5 and Fig. 4-2).

The average linear velocity of the shot through the power position, and the relative height of the shot's centre of gravity at the beginning of second double support also showed a statistically significant difference between the two genders to a p-value of ≤0.10. The females had an average linear velocity of the shot of 6.29m/s (±1.08m/s) through the power position compared to a linear velocity of 5.71m/s (±0.56m/s) of the males. The height of the centre of gravity of the shot was held at 71% of the average standing height of the females (±0.05%), whereas the males held the shot at 68% (±0.03%) of their average standing height.

The male shot putters however had a much greater angular velocity of right knee extension as they achieved an angular velocity of 397.31deg/s (±81.24); 79.97deg/s quicker than the angular velocity achieved by the females (317.34±75.69). This difference was found to be significant at the p<0.05 level.

Phase 4: Release

All of the variables measured at release are reported in Table 4-6 along with the calculated means and standard deviations for each. Three out of the 7 release variables showed significant differences between the two genders (Table 4-6). There was a difference of 3.8 degrees in the release angle as the males averaged a release angle of 35.7 degrees compared to the 31.9 degrees that the females averaged. The comparisons of release angles between genders are illustrated in Fig. 4-3 below.

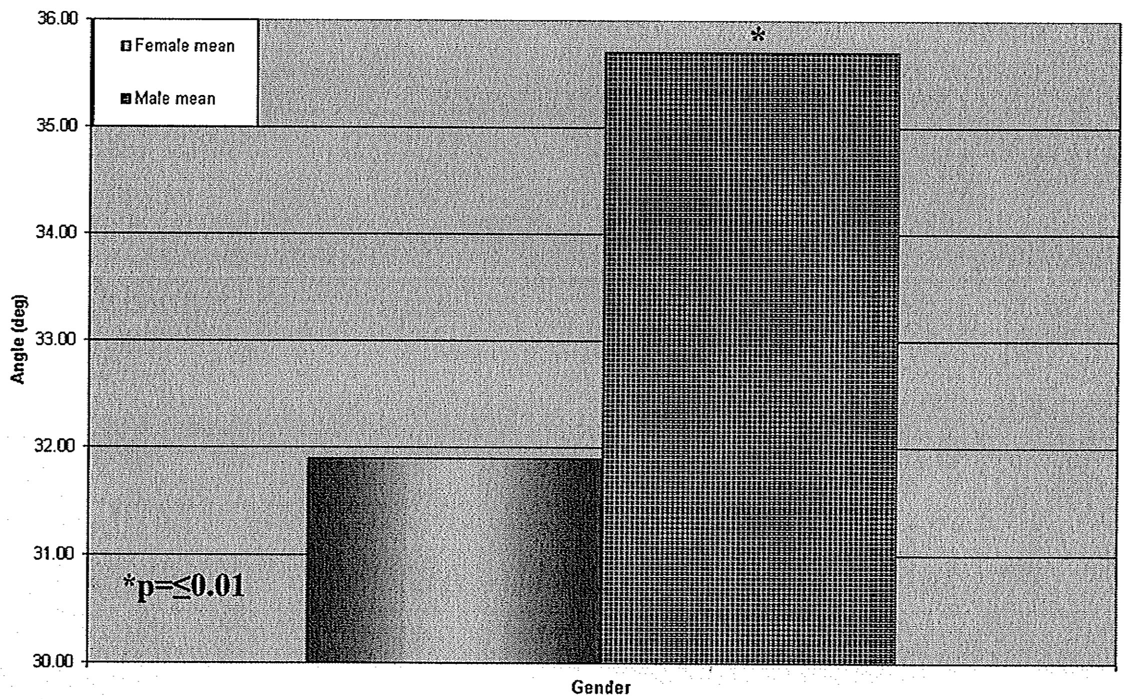


Fig. 4-3: Comparison of the average release angles of males and females.

The male rotational shot putters had a better horizontal release distance as they released the shot 15.27cm (±0.56cm) in front of the toe board compared to the females who released the shot only 9.56cm in front of the toe board. With the difference in the horizontal release distance, it was no surprise that the difference in throw distance between males and females also proved to be statistically significant at a p-value of <0.01 (Table 4-6). The throw distance for the male shot putters ranged from 16.16m to 17.40m with an average distance of 16.92m (±0.44m). The average throw distance for the females was 13.90m (±0.68m) with a minimum throw of 13.03m and a maximum throw of 15.12m. A comparison of the throw distances is available in Fig. 4-4.

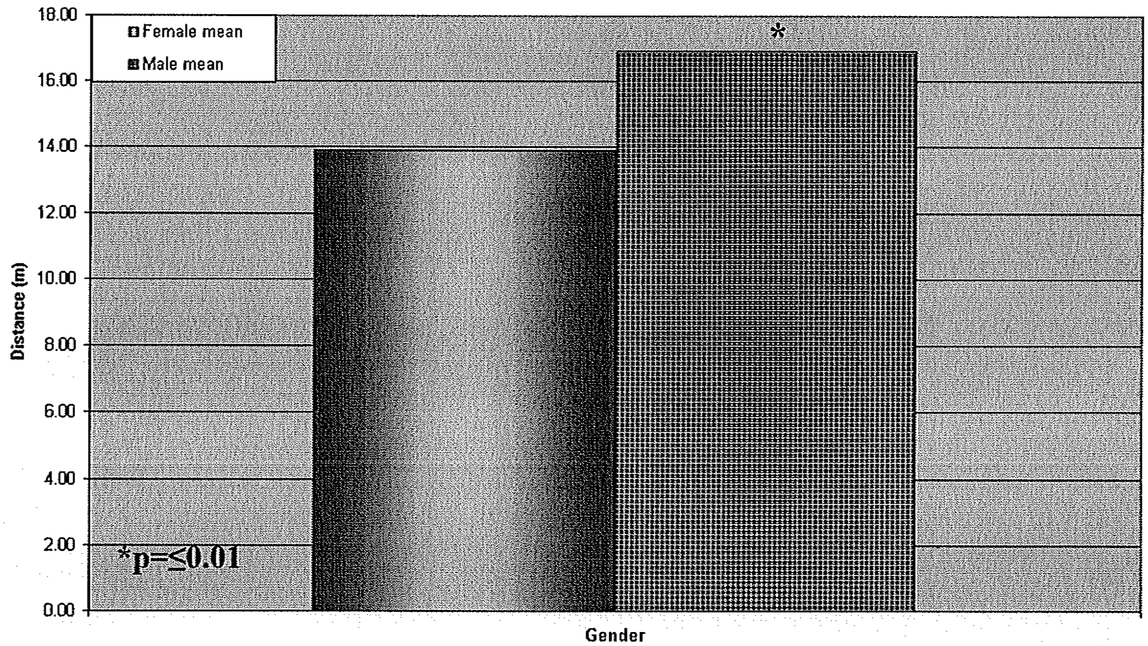


Fig. 4-4: Average throw distance of females and males.

Table 4-6: Comparison of variables measured at release.

Variable	Males N=10		Females N=8		T-value	P-value
	Mean	**SD**	**Mean**	**SD**		
Relative release height	0.88	0.03	0.88	0.06	-0.42	0.41
Release angle (degrees)	35.70	3.56	31.90	3.17	2.39	0.01*
Release velocity (m/s)	10.65	1.24	10.16	1.25	0.83	0.21
Horizontal release distance (cm)	15.27	9.56	0.56	14.61	2.46	0.02*
Distance from toe board (cm)	16.96	10.35	19.50	14.19	-0.42	0.34
Average linear velocity of the shot from SSS-REL (m/s)	3.14	0.34	3.26	0.88	-0.36	0.37

***p≤0.05**

NOTE: SSS = second single-support; REL = release.

Variables measured with the overhead camera

Of the variables measured from the overhead camera (Table 4-7), only one variable, shoulder-hip separation at second single support, was statistically significant at $p<0.10$. The females averaged 40.00 degrees (±12.46 degrees) of separation compared to the male's 24.35 degrees (±0.49 degrees).

Other variables that appeared to be different, but were not found to be statistically significant, were the angular velocities of the hips and shoulders through the power position (from second double support to release). These variables have been graphically represented in Fig. 4-5.

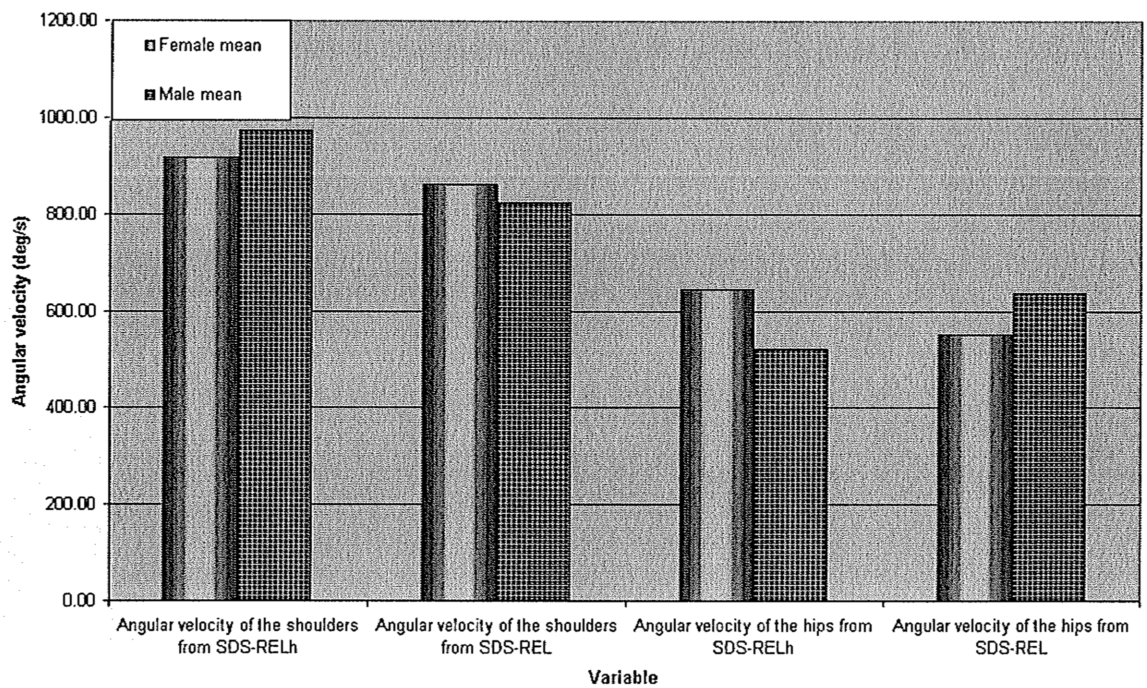


Fig. 4-5: Comparison of key throwing variables that were measured from the transverse camera view. NOTE: SDS = second double support; REL = release; RELh = adjusted position to eliminate over-rotated releases.

Table 4-7: Comparison of variables measured from the transverse camera view.

	Males N=2		Females N=3		T-value	P-value
	Mean	SD	Mean	SD		
Angular velocity of the shoulders from SSS-RELh	637.06	49.14	635.01	52.32	0.48	0.48
Angular velocity of the shoulders from SSS-REL	634.86	93.34	635.70	44.95	0.12	0.50
Angular velocity of the hips from SSS-RELh	586.37	55.84	546.00	73.52	1.48	0.27
Angular velocity of the hips from SSS-REL	549.35	7.43	511.40	77.06	2.18	0.24
Shoulder-hip separation at SSS	24.35	0.49	40.00	12.46	-7.52	0.08*
Angular velocity of the shoulders from SSS-RELh	974.00	109.37	917.50	90.02	5.09	0.30
Angular velocity of the shoulders from SDS-REL	824.31	36.64	860.05	72.49	0.41	0.26
Angular velocity of the hips from SDS-RELh	520.00	123.51	645.28	43.47	-0.49	0.19
Angular velocity of the hips from SDS-REL	636.31	229.80	551.53	54.41	1.40	0.35
Shoulder-hip separation at SDS	66.30	30.97	42.50	3.30	1.21	0.24
Shoulder-hip separation at REL	-23.75	14.78	-16.63	15.47	-0.06	0.32

$*p \leq 0.10$

NOTE: SSS=second single support; RELh = adjusted position to eliminate over-rotated release errors; REL = release; SDS = second double support.

KINEMATIC RELATIONSHIPS WITH THROW DISTANCE

A second purpose of this study was to determine which variables were most related to distance thrown. A Pearson's product moment correlation analysis was conducted separately for males and females to identify the most important variables related to throw distance. Following the correlation analysis, the variables determined to have the greatest effect on throw distance were entered into a forward stepwise multiple regression analysis, and a regression equation for each gender was produced.

Correlation Analysis for Female Throwers

Table 4-8 shows a list of the 8 variables that were found to have the highest correlation to throw distance for the female throwers. The 4 variables with a significant relationship to throw distance were trunk flexion at maximum backswing, relative height of the shot's centre of gravity at first single support, right shoulder abduction at maximum right knee flexion during the second turn, and release velocity.

Trunk flexion was found to have a negative correlation (-0.771) with throw distance as the greater the trunk flexion angle, the shorter the throw distance. Fig. 4-6 represents the relationship graphically.

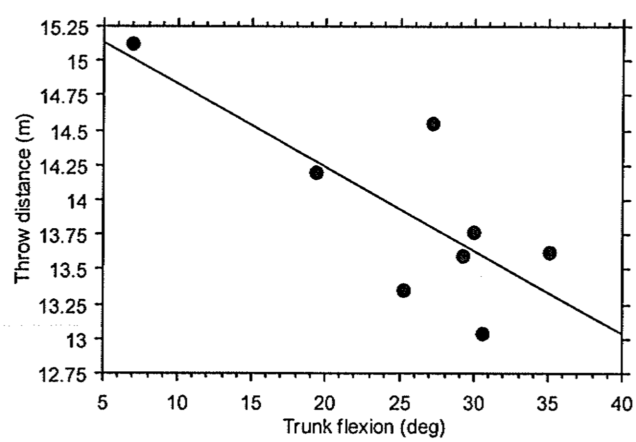


Fig. 4-6: Relationship between trunk flexion and throw distance. R = -0.771; $p \leq 0.05$

Table 4-8: Variables with highest correlation to throw distance for the female shot putters. Relationships are indicated as either positive (+) or negative (-).

Variable	Correlation Females N=8 r-value	p-value
Width of BOS during FDS (m)	-0.560	0.1568
Trunk flexion at MBS (deg)	-0.771	0.0223*
Relative height of shot's centre of gravity @ FSS	-0.678	0.0649**
Right hip abduction during LS (deg)	-0.545	0.1715
Right shoulder abduction at MKF (deg)	+0.664	0.0739**
Horizontal release distance (m)	+0.560	0.1568
Release velocity (m/s)	+0.646	0.0858**
Relative release height	+0.535	0.182

***p≤0.05**
***p≤0.10**

NOTE: BOS = base of support; FDS = first double support; MBS = maximum backswing; FSS = first single support; LS = leg sweep; MKF = maximum knee flexion; SDS = second double support.

The relative height of the shot's centre of gravity at first single support was also negatively correlated to throw distance for female throwers as the lower the relative height of the centre of gravity, the greater the distance thrown. This relationship was found to be significant at a p<0.01 as shown in Fig. 4-7.

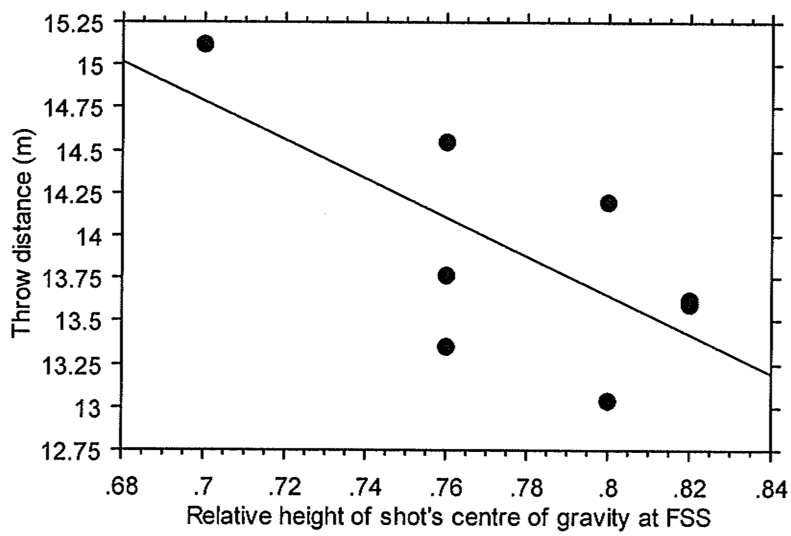


Fig. 4-7: Relationship between the relative height of the shot's centre of gravity at first single support and throw distance. R=-0.678; p<0.10

The right shoulder abduction at maximum right knee flexion and the release velocity both showed a significant positive relationship with throw distance at p<0.10. Figures 4-8 and 4-9 plot the relationships between the right shoulder abduction angle at maximum right knee flexion and release velocity to throw distance. The other variables shown to have strong, but non-significant correlations to throw distance were: width of the base of support during the first double support phase (r=-0.56); right hip abduction during leg sweep (r= -0.545); Horizontal release distance (r=0.56) and relative release height (r=0.535).

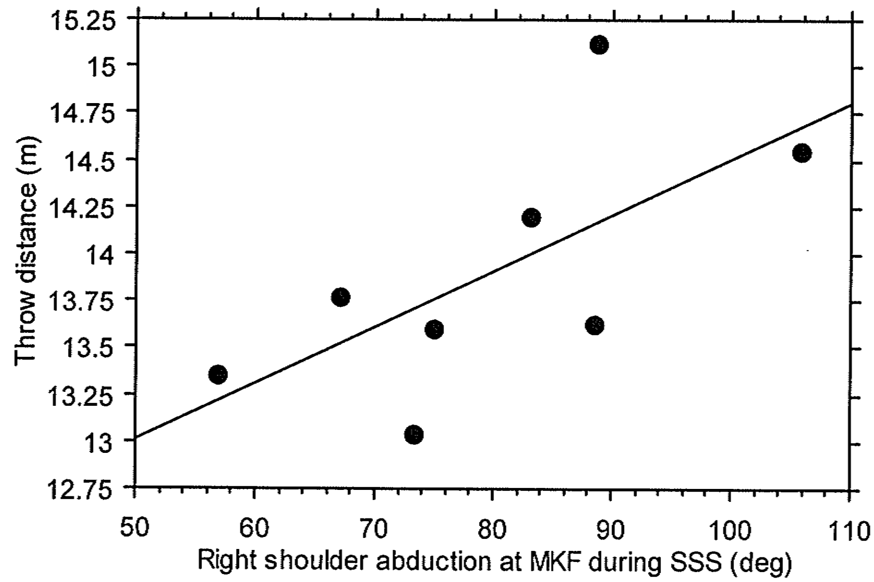


Fig. 4-8: Relationship between right shoulder abduction at maximum right knee flexion and throw distance for female subjects. R=0.664; p<0.10.

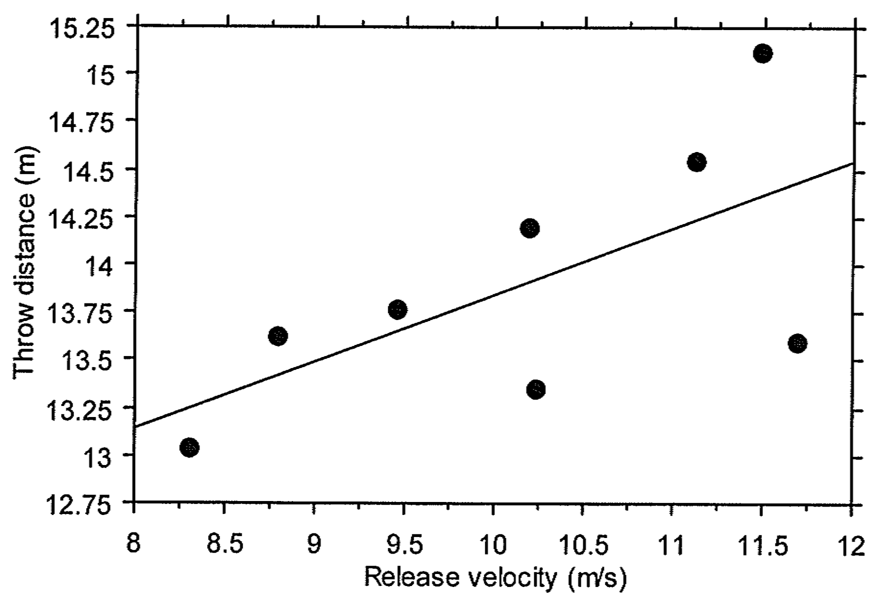


Fig. 4-9: Relationship between release velocity and throw distance for female subjects. R=0.646; p<0.10.

Correlation Analysis for Male Throwers

The correlation analysis was then performed on the data collected from the ten male subjects, and only 2 variables produced a significant relationship to throw distance (Table 4-9). These two variables were release angle and release velocity. The release angle had a correlation coefficient of 0.569 which was found to be significant at $p<0.10$ (Fig. 4-10).

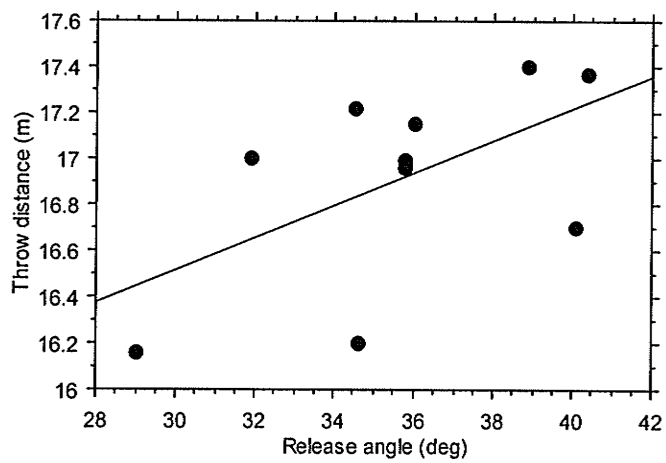


Fig. 4-10: Relationship between release angle and throw distance for male subjects. R= 0.569; p<0.10.

The release velocity also showed a high positive correlation to throw distance (r=0.602) (Fig. 4-11).

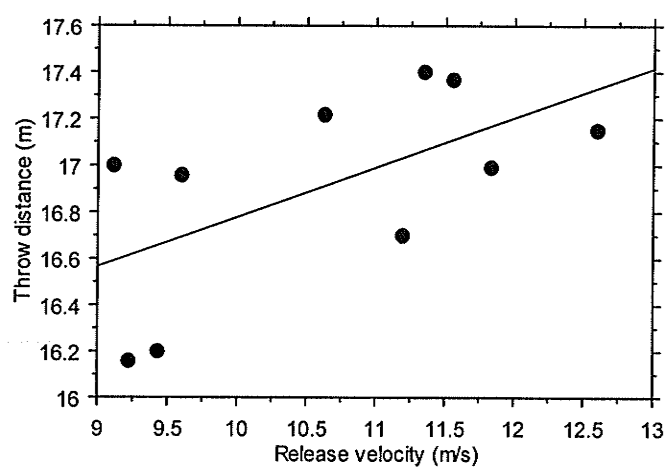


Fig. 4-11: Relationship between release velocity and throw distance for male subjects. R=0.602; p<0.10.

Table 4-9: Variables with highest correlation to throw distance for the male shot putters. Relationships are indicated as either positive (+) or negative (-).

	Correlation Males N=10	
Variables	**r-value**	**p-value**
Average linear velocity of the shot from SSS-REL (m/s)	0.469	0.1780
Trunk flexion angle at MKF during SSS (deg)	-0.481	0.1658
Right knee angular velocity during force production (deg/s)	-0.507	0.1394
Release angle (deg)	+0.569	0.0877*
Release velocity (m/s)	+0.602	0.0654*

$^*P \leq 0.10$

NOTE: SSS = second single support; REL = release; MKF = maximum knee flexion.

The only other variable to show a strong correlation to throw distance was right knee angular velocity during force production which had a correlation coefficient of -0.507. However, this variable proved not to be statistically significant at $p<0.10$.

Re-analyzing some independent variables after removing outliers yielded interesting results. An outlier is an atypical observation that deviates from a pattern established by the vast majority of observations. "Outliers have a profound influence on the slope of the regression line and consequently on the value of the correlation coefficient" (*Outliers,* 2003).

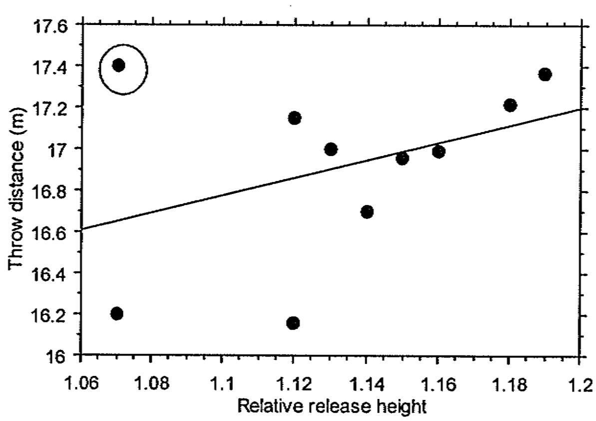


Fig. 4-12a: Relationship between relative release height and throw distance using all ten observations. R=0.309; insignificant.

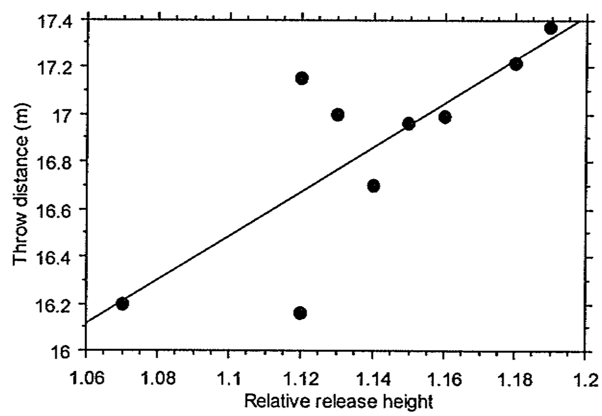


Fig. 4-12b: Relationship between release height and throw distance with the removal of one outlier. R=0.780; $p<0.01$.

Removing one outlier drastically changed the relationship for several other independent variables with the throw distance. However, the values that were removed from each comparison were not consistently from the same subject and therefore this technique was not used extensively. Larger sample sizes are required in order to determine whether or not these observations truly are outliers. For example, when plotting relative release height against throw distance, the removal of one outlier changed the correlation coefficient from 0.390 to 0.780 (Fig. 4-12a and 4-12b).

Variables from Transverse Camera View

All of the independent variables measured with the overhead camera were pooled into one group and correlated with throw distance. The one variable that had a significant difference between the males and the females (shoulder-hip separation at second single-support) was removed and was not correlated with throw distance as the sample sizes were too small to show any relationships. Although many of the variables showed a strong correlation with throw distance (Table 4-10), only one independent variable proved to be statistically significant; the angular velocity of the shoulders from second single support to release (r= 0.862; p<0.10) (Fig. 4-13).

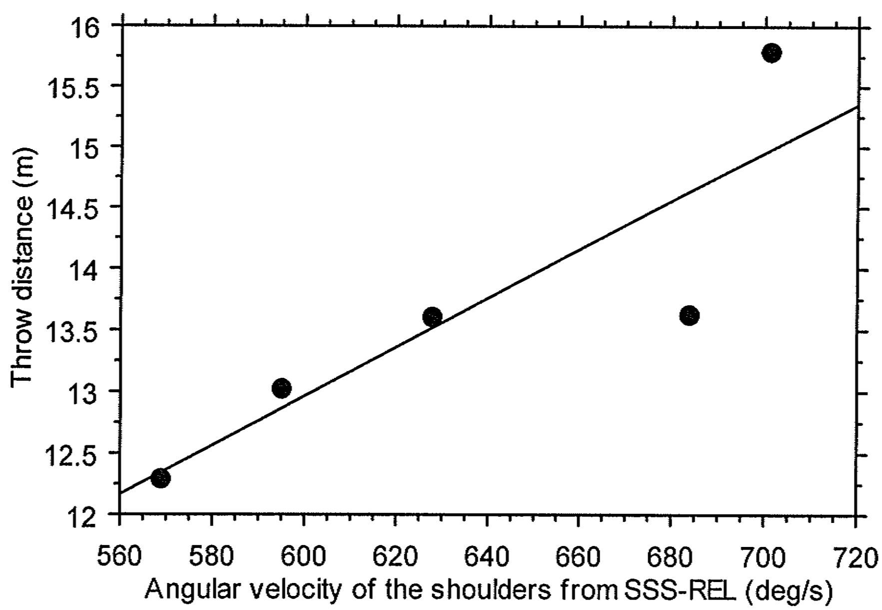


Fig. 4-13: Relationship between angular velocity of the shoulders from second single-support (SSS) to release (REL) and throw distance. R=0.862; p<0.10)

Table 4-10: Correlations of variables measured using the transverse camera view with distance thrown.

	Correlation N=5	
	r-value	**p-value**
Angular velocity of the shoulders from SSS-RELh	-0.675	0.2465
Angular velocity of the shoulders from SSS-REL	0.862	0.0658*
Angular velocity of the hips from SSS-RELh	0.636	0.2877
Angular velocity of the hips from SSS-REL	0.311	0.6490
Angular velocity of the shoulders from SDS-RELh	-0.458	0.4843
Angular velocity of the shoulders from SDS-REL	0.213	0.7599
Angular velocity of the hips from SDS-RELh	0.440	0.504
Angular velocity of the hips from SDS-REL	-0.690	0.2307
Shoulder-hip separation at SDS	-0.532	0.4017
Shoulder-hip separation at REL	-0.474	0.4667

$^*p \leq 0.10$

NOTE: SSS=second single support; RELh = adjusted position to eliminate over-rotated release errors; REL = release; SDS = second double support.

STEPWISE MULTIPLE REGRESSION ANALYSIS

To conclude the statistical analysis of the study, two separate stepwise multiple regression tests were performed on females and males in order to determine the weighting of each variable's effect on throw distance. All of the variables were entered into each equation.

Female Regression Equation

Analysis of the female rotational shot putters identified six variables that were important in predicting throw distance. The 6 variables identified by the stepwise regression analysis as the group of variables that together explain nearly all the variance within the throw distance are listed in Table 4-11. Only 5 of these variables were included as the first five variables explain throw distance to an R=1.0. These five variables are expressed in the regression equation for the prediction of the dependent variable in Fig. 4-14.

Table 4-11: Results of the forward stepwise regression analysis on the female data. Summary of the 5 variables included in the regression equation.

Variables	Coefficient	Std. Error	Std. Coefficient	F
Right knee angle at power position	.074	0.001	1.021	3058.683
Maximum right knee flexion at second turn	-0.005	0.001	-0.058	18.920
Right knee flexion at second single support	0.014	0.001	0.115	117.941
Right hip abduction during leg sweep	0.027	0.001	0.451	550.237
Trunk flexion at maximum backswing	-0.145	0.002	-1.875	6001.452
F to enter = 4.000				
F to remove = 3.996				

Regression equation:

$$y = 12.204 - 0.145X_1 + .074x_2 + 0.027x_3 + 0.014x_4 - 0.005x_5$$

Where:

Intercept = 12.204

y = throw distance

X_1 = trunk flexion during maximum backswing

X_2 = right knee angle at power position

X_3 = right hip abduction during leg sweep

X_4 = right knee flexion at second single support

X_5 = maximum right knee flexion during second turn

Fig. 4-14: Regression equation to predict female throw distances.

Male Regression Equation

Regression analysis of the male rotational shot putters identified 8 variables however only 7 of these variables were included in the regression equation as the 7 variables explain over 99% of the variation in throw distance. These variables are listed in Table 4-12 and the regression equation is displayed in Fig. 4-15.

Table 4-12: Results of the forward stepwise regression analysis on the male data. Summary of the 7 variables included in the regression equation.

Variables	Coefficient	Std. Error	Std. Coefficient	F to remove
Release velocity	0.650	0.011	1.835	3266.924
Right knee angle at power position	-.022	0.003	-0.445	68.024
Relative ht. of shot's centre of gravity at the beginning of second single support	-5.810	0.244	-0.346	566.171
Maximal right hip flexion during the second turn	0.059	0.003	1.507	460.966
Angle of the trunk to the right of vertical at leg sweep	-0.10	0.001	-0.244	161.733
Right shoulder abduction at first single support	-0.059	0.001	-1.430	4011.344
Width of base of support at second double support	-0.014	4.617E-4	-0.396	888.452

F to enter = 4.000
F to remove = 3.996

Regression equation:

$$y = 17.388 - 5.810X_1 + 0.650X_2 - 0.100X_3 + 0.059X_4 - 0.059X_5 - 0.022X_6 - 0.014X_7$$

Where :

Intercept = 17.388

X_1 = relative height of shot's centre of gravity at the beginning of the second double support phase

X_2 = release velocity

X_3 = angle of trunk to the right of vertical at leg sweep

X_4 = maximal right hip flexion during second turn

X_5 = right hip abduction during leg sweep

X_6 = right knee angle at power position

X_7 = right shoulder abduction at first single support

Fig. 4-15: Regression equation to predict male throw distances.

CHAPTER V

DISCUSSION

Men and women both compete using the rotational shot put technique; however, considering physiological gender differences and the differences in shot weight, it would be erroneous to assume that they both use the same technique. The purpose of this study was to determine the kinematic differences between male and female techniques and to establish which variables are of most importance to each gender in terms of throw distance. Recognizing that there are technique differences between the genders would help coaches and athletes in the sport to better understand the technique and allow them to better focus their training.

This study analyzed all phases of the rotational shot put technique including: Backswing, First turn, Second turn and Release. Numerous variables from each phase were measured using Dartfish 4.0.7 and statistical analysis was performed to determine which variables differed significantly between the genders, which variables were most related to throw distance, and which variables best predicted throw distance. Throw distance was selected as the outcome or dependent variable as it determines the degree of success of each throw. Release velocity was not chosen as the dependent variable because release velocity alone does not explain differences in throw distances. Angle of release and height of release are also major contributors (Hay, 1993). Moreover, release velocity is, "the product of the prior actions rather than as a means to an end itself" (Young, 2004 p.5300). These other factors are not yet known or fully understood and need to be explored.

BACKSWING PHASE

For all shot putters, male or female, glide or rotational, the backswing occurs with the athlete facing the back of the circle and the shot held securely in place. The similarities, however, end there. In almost all other sport skills, the purpose of the backswing is to stretch the muscles that will be used to generate force during the force producing phase of the skill and to increase the range of motion for the force producing phase (Alexander, 2002; Hay, 1993). In the rotational shot put technique, the second single-support phase is the point in the skill when the athlete actually wants to get into a position in which the muscles are maximally stretched for the final force producing phase of the skill. At the elite level, the backswing of rotational shot putters can fit into one of two categories; a high backswing, where the athlete stands more upright with the knees and hips extended, or a low backswing in which the athlete has a lower centre of gravity and more flexion in the hips and knees.

In terms of the backswing techniques used by the subjects in this study, 6 out of the 10 male subjects used a low backswing and the remaining 4 had a distinct high position at maximum backswing. Of the 8 female subjects, the ratio was 1:1 as 4 subjects used the high technique and 4 used the low technique.

There were 6 variables measured during the backswing phase of the skill however, none of the variables produced a significant difference between the male and female techniques. When taking into consideration the different backswing techniques used within the male and female groups, it is understandable that there were no significant differences between the genders. For example, when comparing the means of knee flexion angles, males averaged 57.11 degrees of knee flexion whereas the females averaged 70.51 degrees. The 13.4 degrees difference however, was not found to be significant at $p \leq 0.10$ as the standard deviation for each group was over 20 degrees. Many of the other variables measured during the backswing phase also had high standard deviations within each gender category. High standard deviations are an indication that the observations are widely dispersed. In other words, the larger the amount of variation presented in a set of data, the larger the value of the standard deviation (Hassard, 1991).

Statistics aside, qualitative analysis of the two groups during this phase of the skill suggested that all of the females had a full backswing as they rotated their hips and shoulders to the right (all subjects were right-handed throwers) to increase their range of motion in the first turn (Fig. 5-1, frame 1). Two of the 10 male subjects did not have any backswing as their hips and shoulders remained almost square to the back of the circle (Fig. 5-1, frame 3). Another 3 males only used half of a backswing as they rotated their shoulders to about 90 degrees with minimal hip rotation as seen in Fig. 5-1, frame 2.

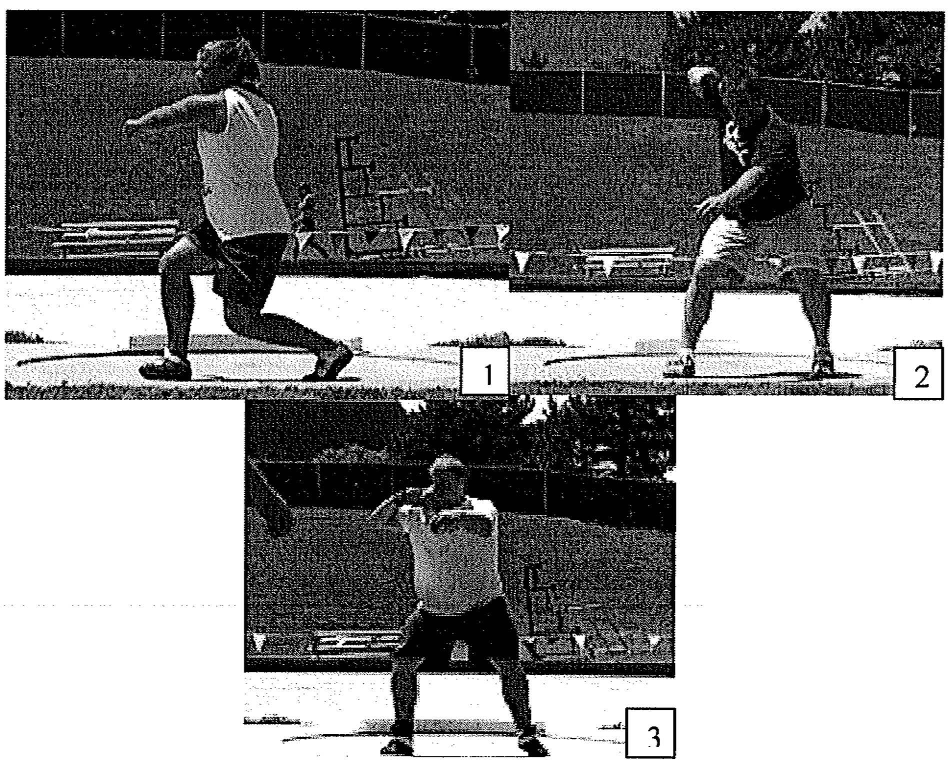


Fig. 5-1: A comparison of backswings. Athlete 1 is considered to exhibit a full backswing, whereas athlete 2 is considered to exhibit half of a backswing and athlete 3 no backswing.

Elite shot putters, whether gliders or rotators, use a full range of motion during their backswings. The flexibility of the athlete will partly determine the extent of their backswing, along with their anthropometry. Athletes carrying more weight in their mid-section will not be able to produce as great a shoulder-hip separation as large as other athletes with less soft tissue in the area, and will have a smaller range of motion that they can move through. This is not the case for the male subjects in this study who did not use a backswing, as the two subjects were relatively lean. For this reason, the lack of a backswing would be considered an error in their technique as they have missed an opportunity to increase the range of motion to generate force during the first turn.

All of the subjects, males and females had their right shoulder abducted close to 90-degrees and the left shoulder was flexed close to 90-degrees. Some subjects had their left arm horizontally abducted so that the left arm was in a position across their chest (all of the females reached this position), and some subjects only had shoulder flexion. Even at the elite level, there is variation in the placement of the left arm. The available literature on the rotational shot put technique does not provide any insight into the correct positioning of the left arm, other than Rasmussen (1998) who suggested that the shoulders should be level during the backswing.

Interestingly, females' trunk flexion at maximum backswing was found to have a significant negative relationship to throw distance (r=-0.771). Thus, the greater the trunk flexion of the female throwers at the peak of their backswing, the shorter their throw distance was. Combining the findings of the correlation and the qualitative analysis, there is a possibility that the a greater trunk flexion angle made it more difficult for the female throwers to get out of the more "coiled" position they reached at maximum backswing (Fig. 5-2).

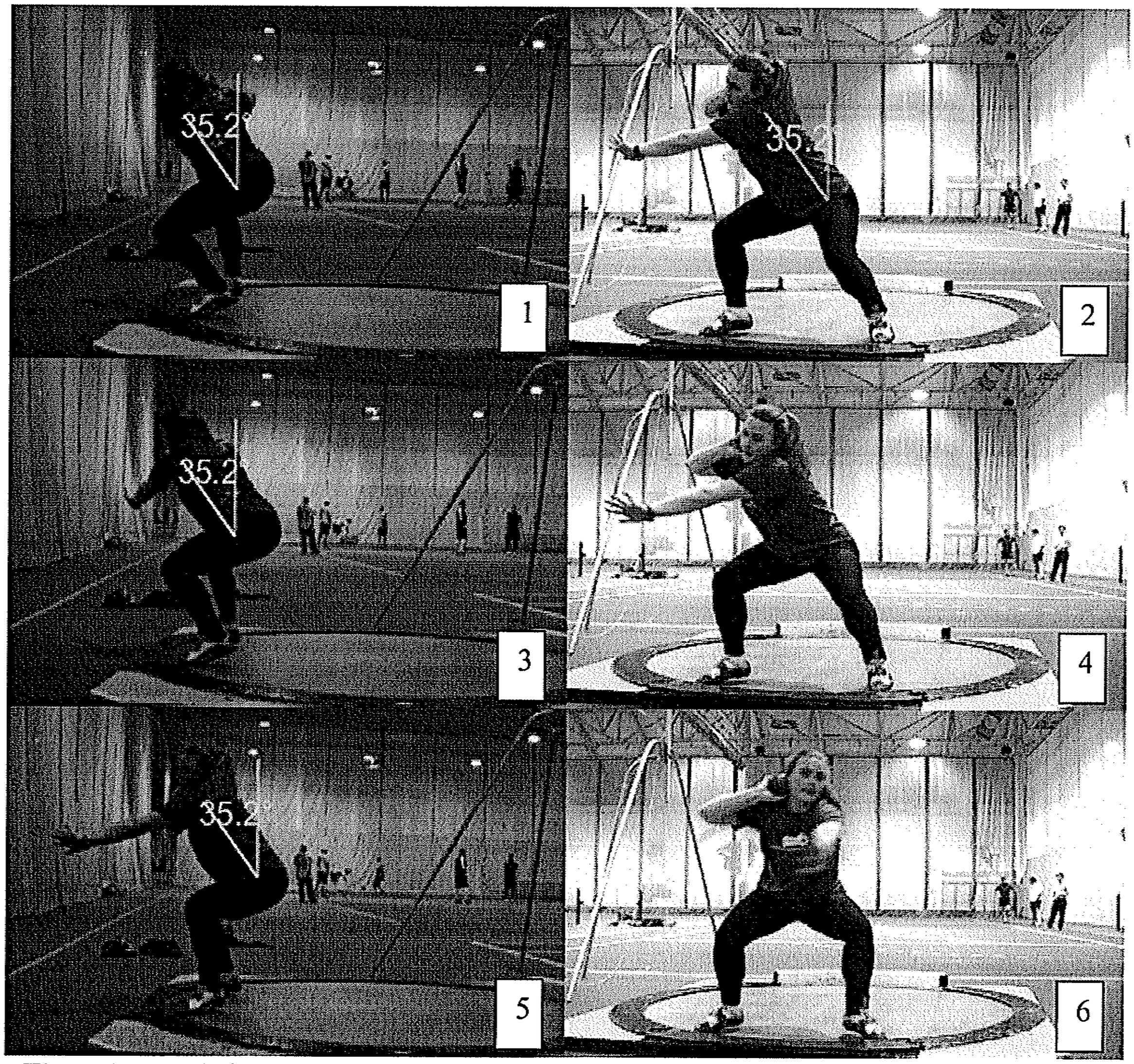


Fig. 5-2: Trunk flexion of a female athlete as she "uncoils" from maximum backswing.

Provided the athletes' axis of rotation is vertical at this phase in the skill, an increase in trunk flexion angle would increase the moment of inertia around this axis. This means that the trunk muscles would be required to exert greater force in order to achieve an equal angular acceleration given a larger moment of inertia as the muscles would have to exert a greater amount of torque ($Fd_{\perp} = I\alpha$). In essence, a greater trunk flexion can create too large a moment of inertia and slow down the turn. Further research into the relationships between backswing variables and variables of the first and second turn are required in order to determine the validity of this theory.

None of the variables in maximum backswing had any significant relationship with throw distance for males. This is not surprising considering the variation in backswing within the group and the lack of variation in throw distance.

FIRST TURN

The first turn begins after maximum backswing has been reached and includes all of the phases up to second single-support phase. Therefore, the first turn includes: first single-support phase, "leg kick", takeoff, and a brief airborne phase (Fig. 5-3).

The first turn serves two main goals. One goal is to accelerate the shot and produce angular momentum as the athlete moves into the second turn (Young, 2004). The second goal of the first turn is to place the athlete in an optimal position at second single support (the beginning of the second turn) which is the point at which athletes using the rotational technique should have the advantage over shot putters using the glide technique (Hay, 1993). Errors in the first turn have a profound effect on the success of the second turn and the overall throw itself (Bosen, 1985; Palm 1991; Bartonietz, 1994; Luhtanen et al. 1997).

Following a transfer of weight to the left leg, the throwers move into first single support as the right leg is lifted from the ground. Comparing the relative height of the shot's centre of gravity at this phase in the skill, the females held the shot significantly higher than the males. This is not surprising as 7 out of the 8 female participants raised their hips and extended their left knee as the right foot was removed from the ground. This is an indication of lack of skill because it produced too much upward movement in this phase and not enough drive through the circle. Only 2 of the 10 male throwers raised

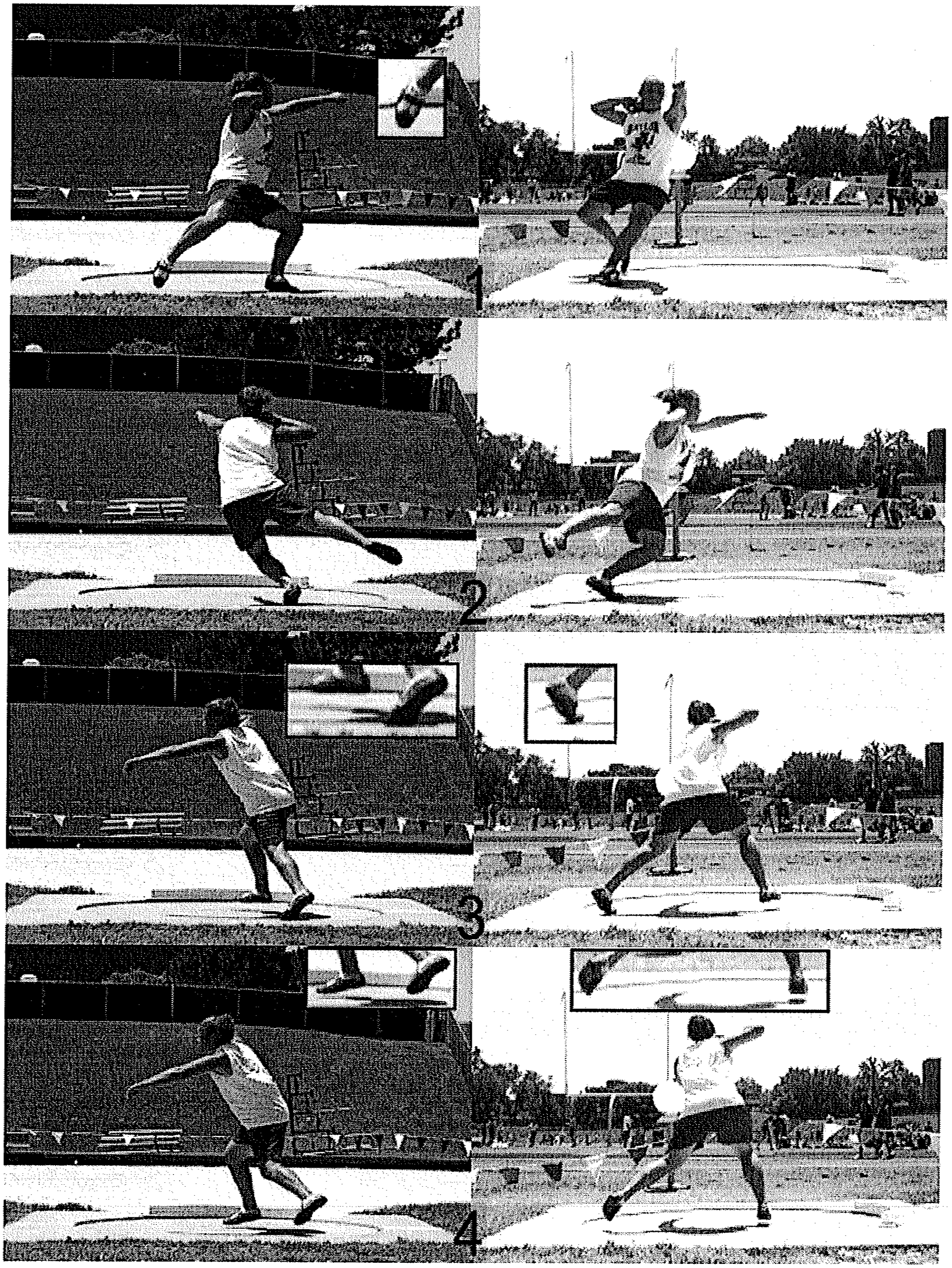


Fig. 5-3: Four phases in the first turn: First single support (1), "Leg kick" (2), Takeoff (3), Airborne (4).

their hips as 5 of the males kept their hips at the same level as in first double support and 3 of the males actually lowered onto their left leg by increasing flexion in their left knee. The difference in relative shot height between males and females suggests that the females may not have the quadriceps strength to maintain the lower position. However, elite female shot putters keep their hips at the same level in the first turn until the takeoff phase of the skill (Fig. 5-4). In addition, the relative height of the shot's centre of gravity at first single support had a significant negative relationship to throw distance, as the higher the shot was held at this phase in the skill, the shorter the throw distance (see Table 4-8). Thus, the increased vertical height of the athletes' hips is considered to be a technique error of the female subjects in this study that may be related to their lower strength levels.

Fig. 5-4: The hips remain at the same level as this elite female rotational shot putter shifts her weight onto her left leg and moves from the first double support phase to the first single support phase.

As the athlete begins to rotate, the shoulders should be kept at the same level and the shoulders, torso and hips should rotate together (Palm, 1991; Bartonietz, 1994; Dziepak, 1998; Pagel et al., 2003). With the exception of one thrower who had a small negative shoulder-hip separation at first single support, the females rotated their left side as a single unit correctly. Three of the females began their rotation with a flat foot which is a common error in young rotational shot putters (Pagel et al., 2003) (Fig. 5-5). Not only can this unnecessarily decrease the speed of rotation, but this places a torsion stress on the left knee.

Eight of the 10 male throwers in this study rushed through the first turn and allowed their shoulders to rotate ahead of their hips. Once the shoulders are ahead of the hips, the hips have to try to catch up in order to reach a positive shoulder-hip separation at second single support. This causes the athlete to rotate too quickly in the first turn which can lead to an unbalanced position, as the athlete's upper body must wait for the lower body to catch up. Furthermore, as the hips are forced to rotate quickly to catch up to the upper body, the hips will be storing more of the angular momentum into the second turn and will often have to decelerate through the power position as the hips need to be blocked and the rotation stopped in order to have a powerful release.

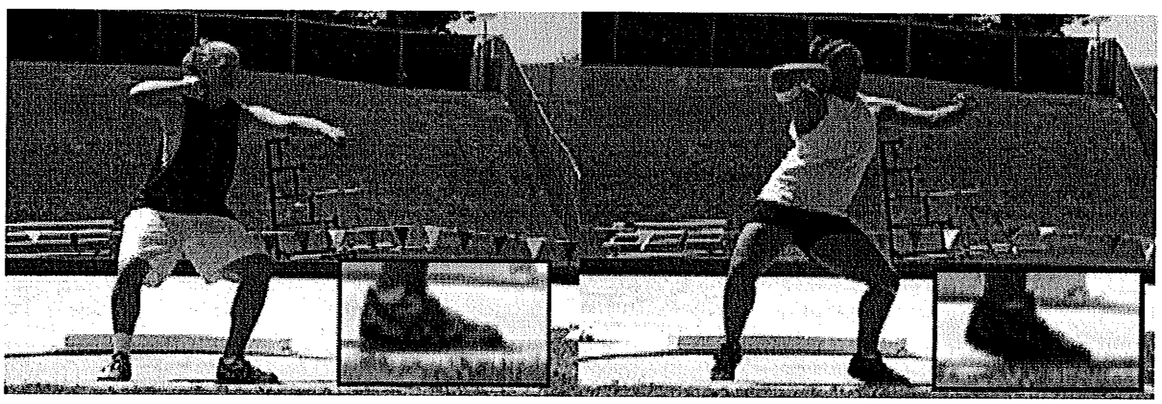


Fig. 5-5: Athlete on the left is beginning her first turn with flat feet compared to the athlete on the right who is on her toes.

A wide sweeping leg has a greater moment arm from the longitudinal axis of rotation through the toes of the left foot, which results in a greater torque being applied by the athlete. An increase in torque over the same time interval of the alternative leg sweep will create a larger change in angular velocity as angular impulse (the product of torque and time) creates a change in angular momentum ($I = Tt = I\omega_f - I\omega_i$).

During the first single-support phase, the throwers use a leg "kick" to help generate angular momentum in the leg that will be transferred to the trunk when the leg stops (Alexander, 2004). There are two variations to the leg kick; a) a wide sweeping right leg that incorporates right hip abduction and (b) a more up and down oriented leg kick that drives the leg down and forward. Five female throwers and all 10 of the male throwers used a wide sweeping leg kick whereas 3 of the female throwers chose to use the second technique.

For female rotators that have difficulty generating angular velocity in the first turn, and for that matter throughout the skill, the low leg kick directed more down and forward would be the appropriate choice of leg kick. When the leg is driven down, the athlete uses a relatively small amount of hip abduction which would minimize the moment of inertia about the longitudinal axis of the trunk. A smaller moment of inertia would make it easier to accelerate around the axis of rotation with any given torque as there would be less resistance to angular motion ($T=I\alpha$).

As many of the males rushed into the first turn, (turned their shoulders before their hips) the low sweeping leg kick is appropriate as the moment of inertia about the longitudinal axis through the trunk is increased and the angular velocity of the turn may be slowed down and better controlled. The more the angular velocity of the first turn needs to slow down, the more hip abduction a thrower will use to increase moment of inertia and decrease angular velocity. The amount of hip abduction used by the males ranged from 11.2 degrees to 51.1 degrees.

Seven of the 8 male throwers that began the first turn too quickly, were not able to correct this error with the leg sweep as they did not increase the hip abduction angle enough. This is indicated by their position at takeoff as they over-rotated. An athlete was considered to have over-rotated when the direction of the takeoff was not directly backwards but directly to the left of the midline (Fig. 5-6). The throwers who were unable to compensate for the over-rotation ended up drifting too far to the left of the midline of the circle.

Fig. 5-6: This athlete has over-rotated prior to the takeoff phase. Extension of the left knee will take him in the direction of the red arrow.

In keeping with takeoff, with the exception of one male thrower, all of the throwers analyzed for this study raised their hips and their centre of gravity before takeoff. A rise in an athlete's hip could be caused by either the athlete forcefully pushing-off from the back of the circle via forceful knee extension, a transfer of momentum from an upsweeping leg, or a combination of the two. For most of the females, the rise in their centre of gravity was the result of a forceful push-off from the back of the shot circle. Elite female rotational shot putters generate more angular momentum with their leg sweep which carries them to the middle of the circle without requiring any added push from the left leg. Right hip abduction angle during the leg sweep is one of the variables included in the regression equation to predict the throw distance for female athletes.

The one male subject who did not have a rise in the height of his hips did not extend his knee and push-off from the back of the circle. Instead, the momentum from his low sweeping kick was enough to carry him to the middle of the circle without any excessive knee and hip movements in the vertical direction. This athlete went on to capture the NCAA Division II shot put championship, suggesting that level hips may be related to better shot put performance. Right hip abduction angle did not come up in the regression equation to predict throw distance. This may be the result of the variability within the male group, or the result of co-linearity with other variables already included in the regression equation.

In terms of the airborne position, the females had relatively level shoulders and there was no excessive body tilt in the air. When looking at the position of the male shot putters however, 7 of the 10 males dropped their left shoulder considerably as the right elbow pointed very high. Fig. 5-7 shows the differences in the airborne position of male and female shot putters. It is not uncommon for young male shot putters to acquire this position as they use their neck to help support the downward forces of the shot in preparation for the landing. It has been suggested by some shot coaches that male shot putters move into this position out of fear of dropping the 7.25kg shot as the drop of the athlete's centre of gravity and the rotation that takes place at second single support creates downward momentum of the shot (Fig. 5-8).

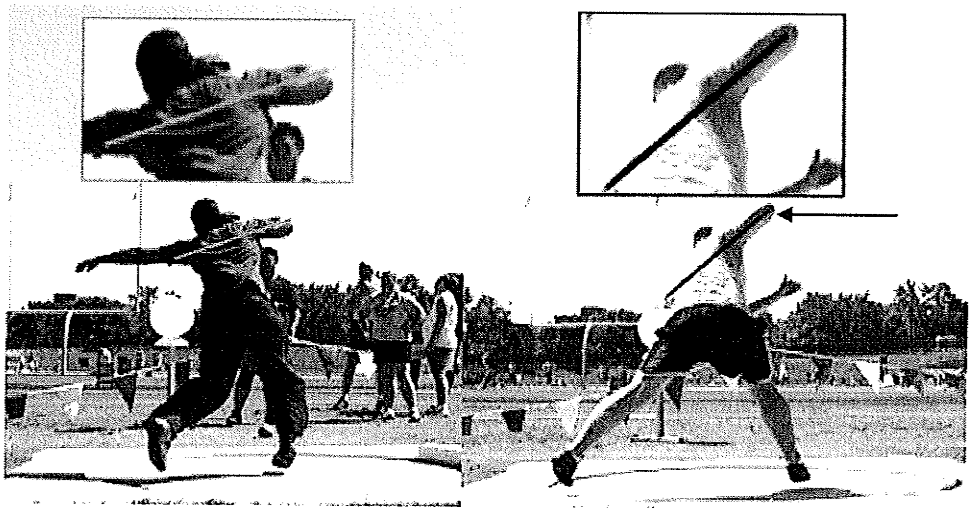


Fig. 5-7: Comparison of the airborne position of females (left) and the majority of the males used in this study. Note the higher tilt of the shoulders and the longer step length of the male athlete (right).

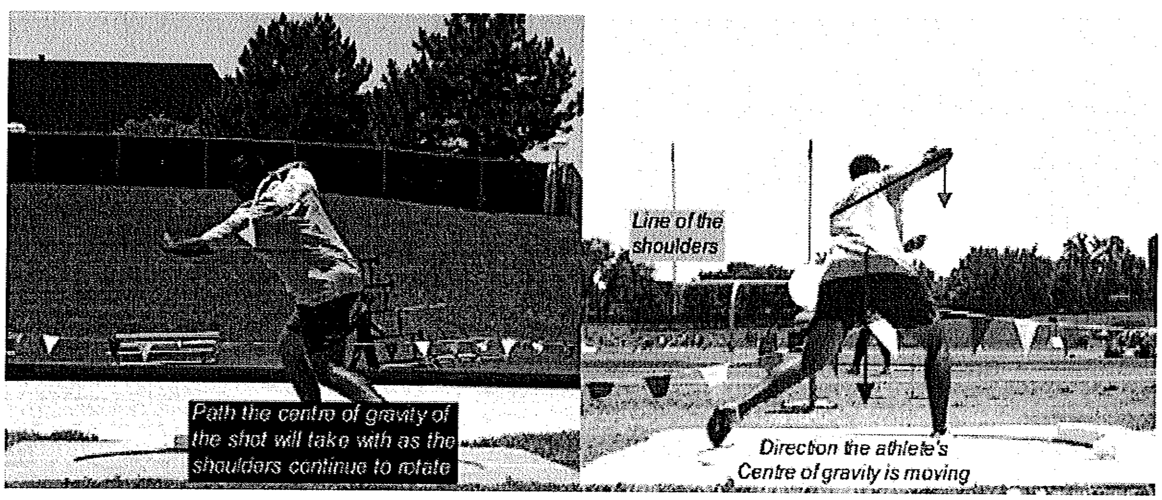


Fig. 5-8: The path of the athlete's centre of gravity is directly down from this point in the airborne phase of the skill. As the shoulder rotation continues, a portion of the resultant velocity of the shot will be directed downwards (green arrow).

The right foot touchdown (second single-support phase) ends the first turn. However, because the position of the body at this point in the skill is a result of the first turn, it will be discussed with the first turn variables.

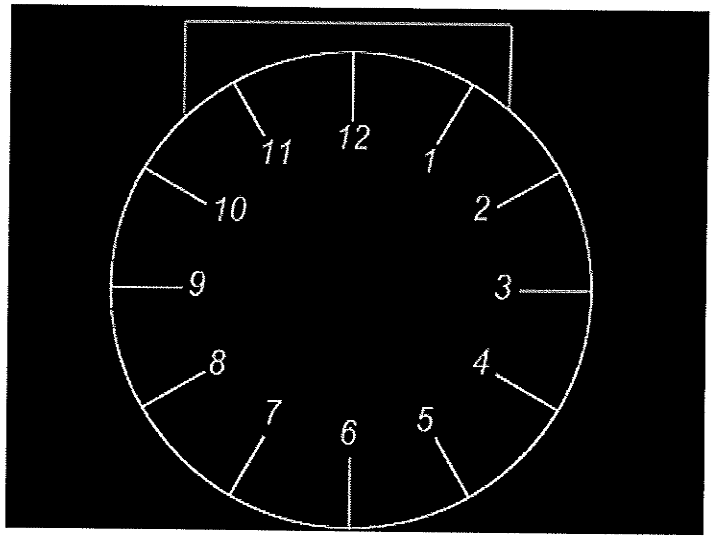


Fig. 5-9: Overhead view of the shot circle with the clock reference used when describing the position of the right foot touchdown.

Ideally, a right-handed thrower should land just past the midline in the centre of the circle with the toes of the right foot pointing between 7 and 9 o'clock (Bartonietz, 1994) (Refer to Fig. 5-9). One of the female throwers landed at 10 o'clock and was too far left of the midline of the circle, however the other 7 female throwers landed within the suggested range and were centered in the circle. By landing between 7 and 9 o'clock, the athletes provide themselves a large range of motion (220 degrees) for the second turn. The athlete who landed at 10 o'clock was left with too much rotation to occur in the second turn to get into the proper throwing position and the friction between the foot and the circle slowed her rotation down too much and decreased her angular velocity through the second turn.

The male throwers in this study landed in various positions in the shot circle as only 3 of them landed along the centre line of the circle, 4 landed to the left of the centre line, and 3 to the right of the centre line. All of the throwers who landed on the left side of the circle were part of the group of throwers that had over-rotated before takeoff and were not able to compensate for the error. In terms of the position of the right foot at touchdown, 2 of the throwers landed at the 5 o'clock position, 1 at the 6 o'clock position, 3 at 7 o'clock, 3 at 8 o'clock and 1 landed at the 11 o'clock position (Fig. 5-10). The 11 o'clock position just amplifies the problems that the 10 o'clock position incurred, however the throwers that landed facing 5 and 6 o'clock have very different problems to deal with. When an athlete lands at the 5 or 6 o'clock position the range of motion available for the second turn is minimized as the athlete has over-rotated during the first turn. Landing at 5 or 6 o'clock can also indicate that too much angular velocity was carried over from the first turn and the thrower will have to be even quicker in the second turn in order to accelerate the shot. Angular acceleration is the rate of change in angular velocity with respect to time ($\alpha = \omega_f - \omega_i / t$), but it is very difficult to accelerate from a high velocity. In addition, landing in a position at 6 o'clock will make a positive shoulder-hip separation more difficult to obtain.

Ideally, the first turn should travel past the midline of the circle and leave the athlete with a smaller base of support for the second turn. A smaller base of support for the power position will allow for a greater release height as the resultant force applied by the athlete to the circle will have a greater vertical component. Five out of the 8 females in this study did not cover half of the circle with their first turn. As mentioned earlier however, one of the goals of the first turn is to place the body in an optimal position for the second turn. The females appear to have focused more on controlling the first turn and maintaining good balance rather than generating a large angular velocity and carrying more angular momentum into the second turn. This is supported by the fact that 7 of the 8 women had proper foot placement in relation to the centre line of the circle, and were well balanced with their foot directly under their centre of gravity. A greater angular

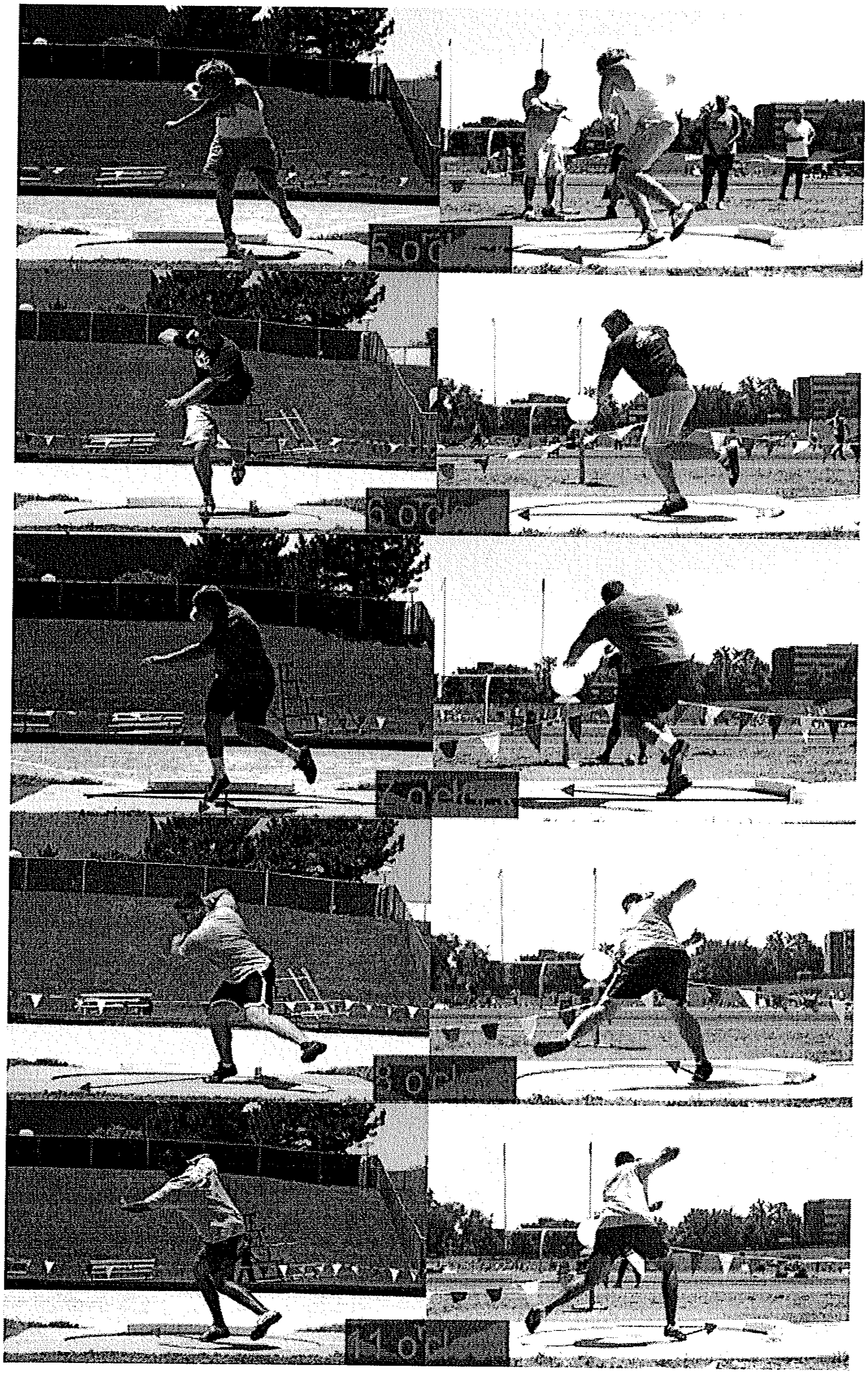


Fig. 5-10: Various positions of right foot touch down at second single support exhibited by the male subjects in this study.

velocity would have helped the females travel more during the airborne phase, as angular velocity would become tangential linear velocity at takeoff since $V=r\omega$ the linear velocity is directly proportional to angular velocity. Elite female rotational shot putters all travel at least halfway across the circle in the first turn. The benefits of a longer "step" into the circle will be discussed with the second turn variables.

Although the male athletes in the study had greater "step" lengths, the direction they traveled across the circle was not beneficial to 7 of the 10 subjects. It is of benefit to throwers to travel in the direction they intend to throw the shot as it makes it easier to stay in balance. An athlete that travels to the left of the centre line of the circle will carry momentum to the left at second single support which will have to be reduced to zero or else the athlete will continue to the left and out of the shot circle. Using the equation: $Ft = mv_f - mv_i$, the athlete must apply a force over given time period to reduce the athlete's momentum (mv_i) to zero. In other words, the athlete must apply an impulse to the ground which will be able to stop linear momentum, the horizontal component of the momentum that would otherwise carry him out of the shot circle. The force that the athlete applies to the ground will be equal and opposite to the direction of the horizontal component of his momentum in order to maintain balance and be positioned to throw the shot within the sector lines (Fig. 5-11).

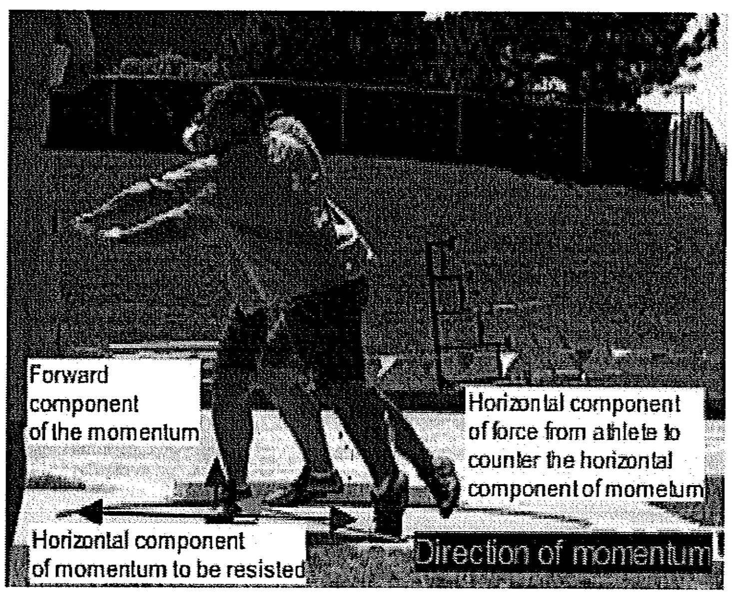


Fig. 5-11: The horizontal component of the momentum must be countered by a force equal and opposite in direction to prevent the athlete from falling out of the circle.

SECOND TURN

Bartonietz (1994) suggests that rotational shot putters should have approximately 60-80 degrees of flexion in their right knee at second single support. It was hypothesized that the males in this study would have a greater knee flexion angle at second single support because males on average are stronger than females. Therefore, the males would be capable of reaching a lower position as they would have more quadriceps strength; a lower position would increase the range of motion the thrower has to accelerate the shot in the vertical direction. However, the females in the study averaged a knee flexion angle of 10.79 degrees more than the men. The females attained 47.48 degrees of knee flexion compared to 36.72 degrees that the males reached. Young (2004) suggested that a greater knee flexion angle at second single support may, "provide an opportunity for the musculature of the (right) leg to function with favorable leverage and operate through the strongest portion of its force curve" (p.5303). The knee flexion angles of both the males and females in this study were both well below the knee flexion angles recommended by Bartonietz (1994), and are considered to be a major technique error of each group.

The relative height of the shot's centre of gravity at second single support was one of the variables included in the regression equation to predict the throw distance of male rotational shot putters in the study. According to the equation, a high shot height in relation to the height of the athlete will result in a significantly shorter throw distance as the coefficient provided by the regression equation was -5.810 (Table 4-12). "A low position of the shot depends primarily on the angle of the strongly bent knee" (Coh & Stuhec, 2005, p.63). As the knee flexion angle is one of the factors that will affect the height of the shot (trunk flexion being the other factor), the lack of knee flexion in the male subjects in this study was poor technique. For the females, the right knee flexion at second single support (Fig. 5-12) was a variable included in the regression equation that had a small but positive effect on the throw distance (0.014). Consequently, second single support is a critical position for both genders, as this position has an effect on the predicted throw distance. However, considering the degree of variation between the techniques of the males used in this study, the significant difference in the knee angles throughout the second turn may not hold true when comparing elite males and females. Nevertheless, coaches of this developmental level may still consider this finding significant, especially if the technique error of the male subjects in this study represent an error in other male shot putters of the same level.

Fig. 5-12: Right knee angle at second single-support measured on a female participant in the study. This variable was one of the variables included in the females' regression equation.

Interestingly, as the second turn progressed, 7 of the 8 female throwers had an increase in knee flexion angle following the initial second single-support phase. When comparing the maximum knee flexion angles of the two groups, the males increased their knee flexion an average of 29.35 degrees to reach a mean of 66.07 degrees. The females only increased their mean knee flexion angle 13.81 degrees to reach a maximum knee flexion angle of 61.29 degrees. The difference in the average maximum knee flexion angles proved to be significant at $p \leq 0.09$ (Table 4-5).

The maximum right knee flexion angle of the females during the second turn was another variable that was included in the regression equation to predict the female throw distance (Fig. 5-13). Unlike the knee angle at second single support that resulted in a greater predicted throw distance, the maximum right knee angle (that occurs after the right foot first lands on the shot circle) had a small but negative effect on throw distance (-0.005). This validates the recommendations of Pyka and Otrando (1991), and Sampson and Chapman (2002) that the knee flexion angle should not increase during the second turn. This variable may have had very little weight in the prediction equation as the increase in the females' average knee flexion angle was only 13.81 degrees (for every degree of knee flexion angle measured at this stage of the skill, throw distance decreased -0.005m).

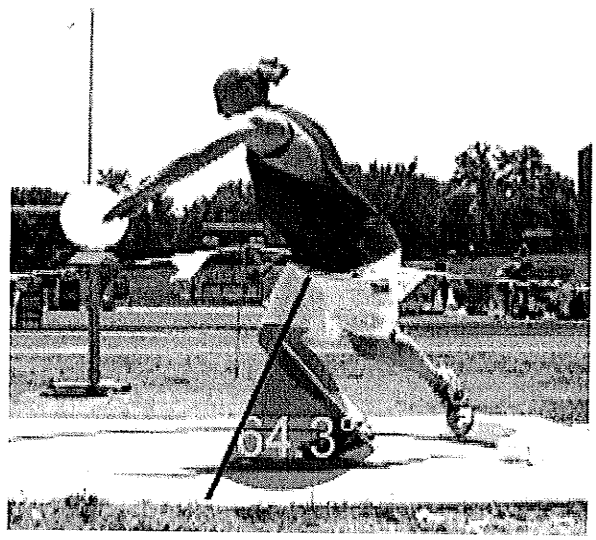


Fig. 5-13: Maximum right knee flexion angle measured on a female participant in this study. This variable was one of the variables included in the female regression equation.

Exploring this difference further, it was found that the males averaged a greater change in the relative height of the shot's centre of gravity from first single support to the takeoff phase (.06) than the females (.02). A greater increase in vertical height suggests that the male throwers may have had a higher airborne phase which may explain why their knee flexion angles increased during second single support as they had to absorb more vertical forces (Fig. 5-14).

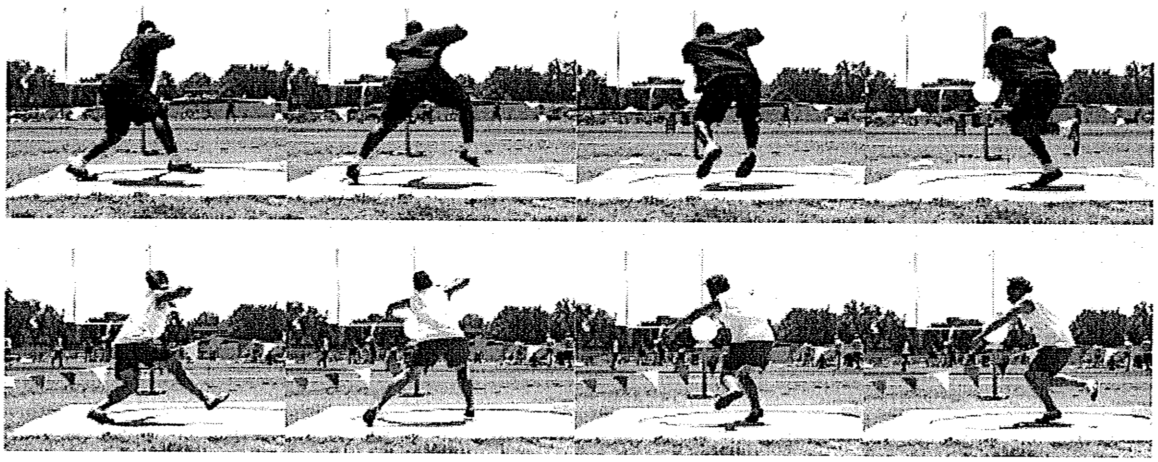


Fig. 5-14: Comparison of the height of the airborne phase between one male and one female shot putter in the study.

The faster a muscle is stretched, the greater the stretch-reflex within the muscle and the faster and more forceful the muscle will contract (Chu, 1998). Therefore, the technique adopted by the male subjects of increasing their knee flexion angle after second single support should benefit their technique. The quadriceps would be forced to elongate as they are eccentrically contracting, and essentially, be able to store more strain energy, allowing for a more powerful concentric contraction. However, Pyka and Otrando (1991), and Sampson & Chapman (2002) suggest that there should be very little increase in knee flexion angle at second single support, if any. Eccentric contractions require a great deal of muscle energy which should be conserved for the concentric contraction of the quadriceps and vertical acceleration of the shot upwards. Therefore, the females may have had better technique as they landed with a greater knee flexion angle; however, they too increased their knee flexion angle as they continued their second turn. More research is needed to determine if there is any advantage to increasing the knee flexion angle at this phase of the rotational shot put, or if indeed it is better to conserve quadriceps energy for the vertical acceleration of the shot.

Although no values for the right knee extension angular velocity were found in the review of the available shot put literature, this variable showed significant differences between the males and females in this study ($p \leq 0.02$) (Table 4-5). The males averaged an angular velocity of 397.31 deg/s compared to the females 317.34 deg/s, a difference of almost 80 deg/s more. One explanation for this difference is the greater degree of maximum knee flexion that the males reached during the second turn which allowed them to move through a greater range of motion to apply knee extension force to the body.

All of the subjects extended their right knee as they moved into the power position. The females extended their knees an average of 4.49 degrees as they moved from 61.29 degrees at maximal right knee flexion to 56.80 degrees of knee flexion at the beginning of the power position. Conversely, the males went from 66.07 degrees to 56.38 degrees – a difference of 9.69 degrees. In analyzing footage of elite male and female rotational shot putters, extension of the knee is rarely observed before the left foot touches the shot circle (beginning of the power position), and when extension in the knee does occur, it is very minimal (Fig. 5-15) . Premature extension of the right knee can be an indication of a lack of quadriceps strength, poor angular velocity in the second turn, poor sequence and timing of events or a combination of any of these errors. The angle of the knee at the power position was almost identical for the females and males in this study (56.80 degrees and 56.38 degrees respectively). Thus, the males have already moved through a greater angular range of motion in their right knee by this point and may have a greater angular velocity of knee extension as they move into the final force producing phase of the skill.

Fig. 5-15: Comparison of the left knee angle in elite rotational shot putters from maximum knee flexion to second single support. Very little change has occurred in the knee flexion angle in all four athletes.

The regression equations to predict the throw distance for the males and the females both included the right knee angle at the power position as a predictor variable. For the female throwers, the greater this angle is, the further the predicted throw distance will be. Conversely, this variable was negatively weighted (-0.022) in the regression equation produced for the males as the greater this angle is, the shorter the predicted throw distance. This may indicate that the females are able to generate a greater angular acceleration at their right knee joint over the final 56.8 degrees of flexion remaining in their knee through the power phase than the males. One possibility is that the males may have generated a greater average angular velocity in their right knee as a result of a high angular acceleration in the knee from maximum right knee flexion. When the males moved into the power position, the males may have already reached peak acceleration and there may have been a deceleration of angular velocity from power position to release.

The females on the other hand may have reached a greater instantaneous angular velocity in the last few degrees of knee extension and the males may have actually had an angular deceleration at the knee joint. Therefore, a greater knee angle at the power position phase of the skill for the male athlete could be an indication that the maximal angular velocity of the right knee has already occurred and the remaining knee extension is an indication of a poor range of motion in knee extension.

The position of the trunk was also measured at second single support when maximum flexion in the right knee was observed, but no differences were found between the genders. In fact, the trunk flexion angles at both of these phases of the skill were within 1 degree of each other with a change of less than 4 degrees as the subjects extended their trunk slightly from second single support to the point of maximum knee flexion. This finding is somewhat surprising considering that the use of the trunk was an area that females may have taken advantage of having a relative longer trunk. The trunk can act as a lever with the shot at one end of the lever and the axis of rotation (the hips) at the other end of the lever. The longer the trunk, the longer the lever, and provided the athlete's trunk muscles are well trained as it would provide a greater radius resulting in a greater linear displacement as $d = r\theta$. This means that the shot could be accelerated over a greater linear distance and could have a greater linear velocity at release as linear velocity is equal to a change in linear displacement over time.

Fig. 5-16: Measurement of maximum hip flexion angle during the second turn.

In terms of the maximum hip flexion angle measured during the second turn (Fig. 5-16); the females had a significantly greater hip flexion angle than the male subjects in this study. As the position of the trunk and the right femur determine the hip flexion angle, the fact males had the same trunk flexion angles as the females, but had a greater maximum knee flexion angle is difficult to explain. However, the large variability within each group may explain the differences. Moreover, the maximal right hip flexion during the second turn was included in the regression equation to predict throw distance of the male subjects (Fig. 4-16). The greater the hip flexion angle, the greater the predicted throw distance for the males suggesting that the males made better use of their hip extensors than their female counterparts. Current footage from the 2006 USA Track and Field National Championships was used to obtain hip flexion angle of elite rotational shot putter Adam Nelson. Adam Nelson had a maximum hip flexion angle of 73.0 degrees (Fig. 5-17). However it must be noted, Adam Nelson uses a very different technique than most shot putters in that he has a larger range of motion of all major joints than the average thrower. More research with a larger number of subjects is required in order to validate this finding.

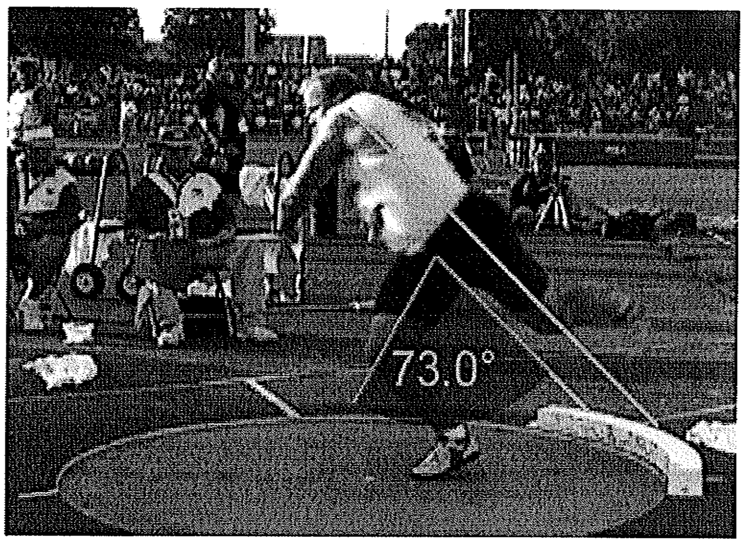


Fig. 5-17: Measured maximal hip flexion during the second turn for elite rotational shot putter, Adam Nelson of the USA.

The placement of the left foot begins the second double support phase of the skill and the position where this foot touches down on the shot circle is very important. The orientation of the feet will have a direct effect on the action of the hips and an indirect effect on the throw distance. As was the case with many of the male subjects, if the left foot is planted too far to the left, then the hips will be opened up too much, which will decrease the effectiveness of the block as the athlete will have a more difficult time stopping the rotation of the hips (Fig. 5-18). On the other hand, some of the male athletes planted the left foot too far to the right and had a stance that was too closed. A closed stance prevents the hips from rotating, and decreases the range of motion of the force producing phase (Fig. 5-18). In addition, an open or closed stance will also make it more difficult to land the shot within the sector lines.

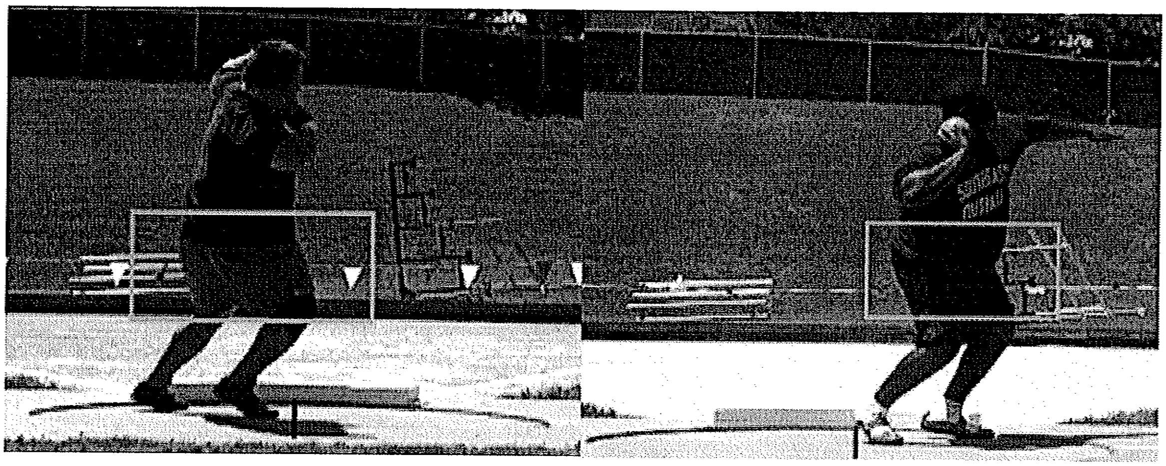


Fig. 5-18: Errors made in the planting of the left foot at second double support; stance is too open on the left picture, and too closed on the right picture.

The length of the base of support was included in the males' prediction equation as the greater the base of support during the second double support phase, the shorter the predicted throw distance would be. This is not unexpected as the wider the base of support, the less the vertical component of the acceleration of the right leg and the less vertical displacement of the shot prior to release (Fig. 5-19). The smaller the vertical velocity, the lower the relative release height will be and the less vertical velocity that will be transferred to the shot at release.

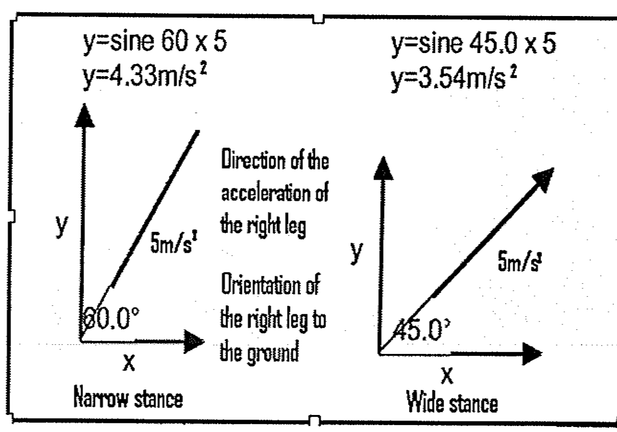


Fig. 5-19: Example of how a smaller base of support can change the resultant velocity and decrease the vertical component.

Both relative release height and vertical velocity of the implement at release are important variables in determining the horizontal distance of a projectile, as both will affect the time in the air of the shot. According to Linthorne (2001) air resistance on a shot is almost negligible, therefore, the horizontal distance of the shot is determined by the equation d=vt; where d = the horizontal distance, v = horizontal velocity and t is equal to the total time in the air. In other words, if two shots are released with the same horizontal velocity, the shot that remains in the air the longest will travel the farthest before making contact with the ground.

At second double support, the females held the shot at 71% of their standing height. The male subjects had the centre of gravity of the shot held at 68% of their standing height which was found to be a significantly lower relative height, than the females (Table 4-5). This is a technique advantage as the lower the shot is at second double support (the power position), the greater the vertical distance the male throwers can accelerate the shot. The greater the distance the shot travels during release, the greater the range the athlete has to accelerate the shot as acceleration is equal to the change in velocity and velocity is equal to the change in displacement. Vertical velocity is a key variable in the flight of a projectile as it will determine the amount of time that the object is in the air ($t_{up} = Vv/g$) (Hay, 1993). Other variables measured at this phase of the skill, lateral trunk flexion angles and knee angles, were found to be very similar between the male and female throwers which may indicate that the amount of trunk rotation may be the determining factor in the difference of relative shot height at this phase of the skill. If the females have the same knee and lateral trunk flexion angles, then the position of the shot in relation to the longitudinal axis of rotation through the trunk may explain the difference in the relative height of the shot. Furthermore, the relative height of the shot's centre of gravity does not factor in differences in limb length which may also explain part of the difference. For example, both the males and females in this study have knee angles of 56 degrees (56.38 degrees and 56.80 degrees respectively), but if the females have a longer relative femur length, then the centre of gravity of the shot would be higher relative to her height, with all else being equal.

Second single-support phase of the skill also showed a difference in the left shoulder flexion used by the males and females in this study. The left arm is used by the athlete to help rotate the trunk. Furthermore, by flexing the left arm, the athlete helps elevate the shoulder girdle as the right arm is already abducted, and this raises the rib cage and allows the shoulder girdle to rotate more freely. The females had an average shoulder flexion angle of 87.86 degrees which was 11.2 degrees greater than the average left shoulder flexion of the males. This difference was significant at $p \leq 0.10$. There is no reason to believe this difference is due to physical male and female differences, but rather, a difference in technique.

It was previously noted that the male throwers were more tilted in the air with their right elbow pointed much higher than the females (Fig. 5-7). Therefore, the line of their shoulders would drop their left arm lower down. From this position, the males decrease their shoulder flexion shortly after and then they use this left arm to help generate more angular velocity of the shoulders as they drive this non-throwing arm up and out. The females rotated in the air in a more upright position maintaining the level of their shoulders closer to parallel with the surface of the shot circle (Fig. 5-20). As throwers move into second double support, they attempt to get into a coiled position and often bring their arms across their body to point backwards. Many of the females changed shoulder abduction into shoulder flexion via horizontal shoulder adduction. The

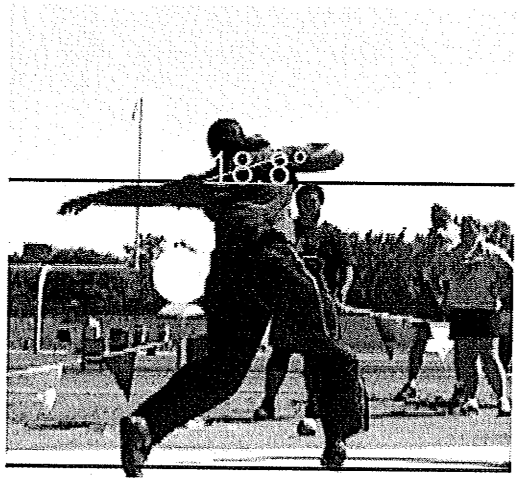


Fig. 5-20: Female shot putter airborne. Shoulder tilt is much closer to being parallel with the surface of the shot circle than her male counterparts.

females appear to be very good at not dropping their left arm. From this position, the females also used their left arm to help generate greater angular velocity of the shoulders. Therefore, the difference in left shoulder flexion angle may in large part be due to some of the technique differences that occurred earlier in the skill.

One variable that had a strong relationship to female throw distance was the angle of right shoulder abduction during the second turn when the right knee was maximally flexed (r=.664) (Fig. 5-21). The maximum right knee flexion angle occurred just before the power position when the athlete is trying to maximize the shoulder hip separation. The reason why the right shoulder abduction angle positively affects the distance the shot is thrown is difficult to know. Ideally, the right shoulder abduction angle should be 90 degrees throughout the entire skill as this would ensure that the arm movements during delivery occur in the transverse plane, rather than in a sagittal plane. The final force producing movements should be horizontal shoulder adduction, elbow extension, pronation and wrist flexion. In the case that an error has been made by the athlete and the shot is released by arm movements such as shoulder flexion in the sagittal plane, the final force producing movements become shoulder flexion, elbow extension and wrist flexion. In the second case, the athlete is now trying to accelerate the shot up vertically via shoulder flexion which is placing considerable stress on the shoulder flexors. Elite shot putters, who release the shot in a more transverse plane, direct the path of the shot upwards by rotating their trunk which is at an angle to the vertical. Therefore, it is the contraction of the many trunk muscles that essentially accelerate the shot vertically and horizontally first, followed by the activation of the shoulder adductors as the athlete horizontally adducts the right shoulder. Therefore, an argument can be made that a good abduction angle in the right shoulder is an indication that the females had better technique throughout the power position in terms of their upper body. It is presumed that this positive correlation to throw distance would not exist if the females in the study had shoulder abduction angles greater than 110 degrees. In this case, this theory of a better technique of the upper body through the power position would not hold true as the humerus would no longer be in correct alignment with the line of the shoulders and more stress would once again be placed on the deltoid muscles of the shoulder.

Fig. 5-21: Right shoulder abduction angle at the point in the skill where maximum knee flexion occurred. The blue line indicates the line of the shoulders.

Linear velocity of the shot through the second turn was found to be significantly different between the males and the females. The females had a greater linear velocity of the shot through the power position despite having a lower release velocity. This finding, however, is a result of the technique used to measure this variable. The linear velocity of the shot actually occurs in a negative direction at second single support as the shoulders rotate, the shot initially moves closer to the posterior aspect of the circle. As the athlete continues to rotate, the shot begins moving in a positive direction. Based on how this variable was measured, this linear velocity measurement is the sum of the positive and the negative velocities. Therefore, a higher positive velocity of the shot can be the result of having a smaller negative velocity phase.

The females' average linear velocity of the shot through the power position was greater at 6.29m/s because the shot was moving towards the front of the circle in a positive direction for a greater percentage of the power position. Coh and Stuhec (2005) conducted a kinematic analysis of an elite Slovene rotational shot putter and calculated his linear velocity through the power position to be 7.02m/s. The methodology used to measure the linear velocity calculated by Coh and Stuhec is unclear; however it is possible that a similar methodology was used as the one in this study as the numbers compare reasonably well. Although comparisons to this value must be viewed with caution, the female throwers in this study had a relatively good linear velocity when taking into consideration the differences in anthropometry. It will be presumed that the elite Slovene shot putter has longer arms, trunk and legs that provided him with longer levers and a greater range of motion to accelerate the shot through the power position. Although the reported linear velocity of the shot calculated in this study may not be an accurate assessment of the linear velocity of the shot through the power position, it was measured in this way to highlight this difference. Another variable should have been calculated and included in this study to break down this velocity into smaller components and acceleration of the shot should have been used.

A smaller negative phase is actually an indication that the athlete did not have the shoulders rotated as far back and therefore had a smaller range of shoulder rotation in the second turn. Ideally though, the more wrapped or "torqued" position the athlete can get in at second single support (Fig. 5-22), the greater the angular distance the athlete can accelerate the shot through and the greater the angular velocity of the shot will have (Dyson, 1973; Sampson & Chapman, 2002). At release, angular velocity of the shot is proportional to the linear velocity of the shot since $V=r\omega$.

Analyzing the video taken of the females and males that participated in this study, the males were able to achieve a more "torqued" position than the females (Fig. 5-22). Data from the overhead camera found that the average shoulder-hip separation of the 2 male subjects was 66.3 degrees, compared to the 42.5 degrees average calculated from the 3 females in the study. Ideally, there should be a 40-60 degree difference (Bartonietz, 1994; Luhtanen et al., 1997). However, due to the large variance between the two male subjects (44.4 degrees reported for one subject and 88.2 degrees for the other), this difference was not found to be significant. Based on the numbers however, both of the males had a greater shoulder-hip separation than the female average.

As mentioned previously, some shot put coaches feel that women are not as successful as the men using the rotational shot put technique because the 4kg shot does not create enough mass and increased moment of inertia to help keep the shoulders back at the second single-support phase. This theory may prove to hold true as the females were unable to achieve the same shoulder-hip separation as the males based on the view from the overhead camera and observation of the other athletes in the study. However more research is required in order to determine if the differences in the shoulder-hip separation are due to the lighter weight shot, or if it is a technique error related to timing

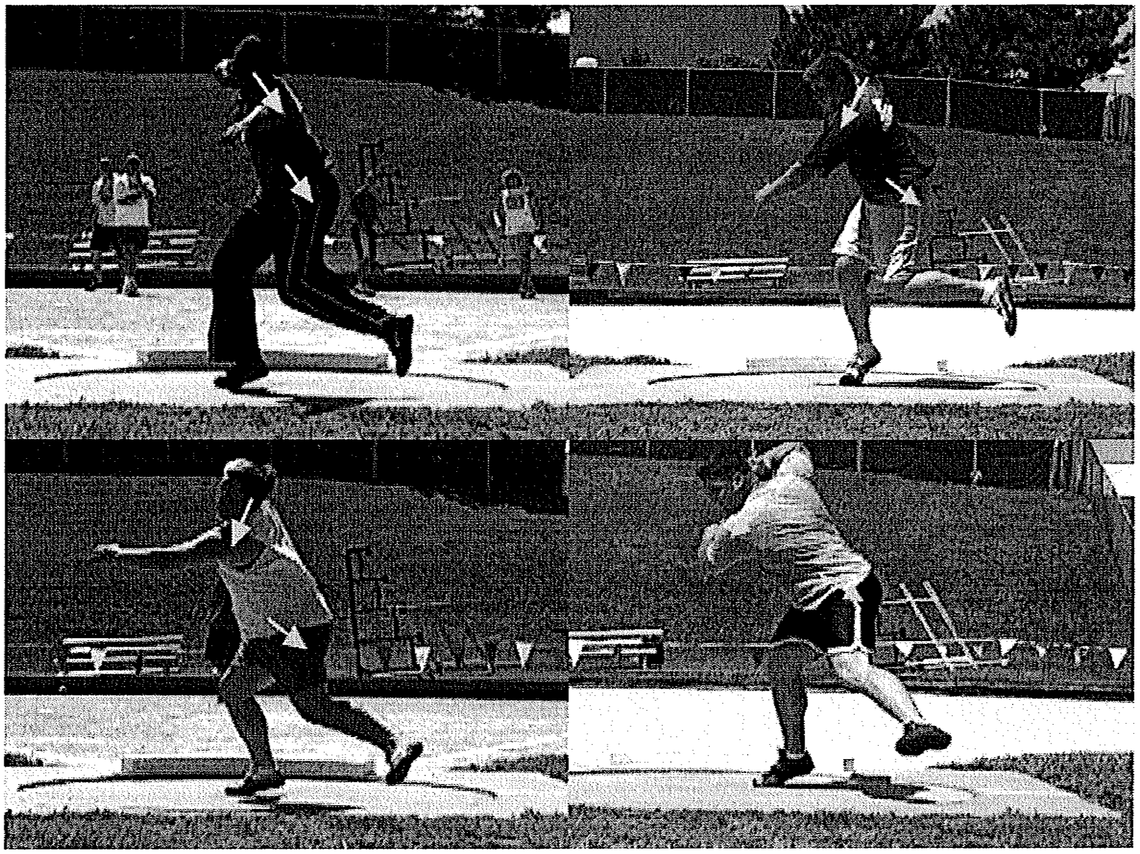


Fig. 5-22: Comparison of the shoulder-hip separations between the female and male subjects in this study during second single support.

and inertial lag of the females in this study.

As there was no significant gender difference in the average angular velocity of the shoulders from second single support to release, this variable was correlated to throw distance by pooling the data collected from all 5 subjects (2 males and 3 females) that were filmed using the overhead camera view. This variable was found to have a high positive correlation to throw distance (r = 0.862) (Table 4-10). In other words, the greater the angular velocity of the shoulders from the second single-support phase to release, the farther the throw. Thus, the importance of the landing in a good position during second single support with the shoulders rotated well back cannot be emphasized enough.

RELEASE

The differences in throw distance between the males and the females can be partially explained by two technique errors made by the female throwers in this study: 1) the females did not have a horizontal release distance of the recommended 20-50cm (Young, 2004) and (2) the females released the shot at a significantly lower angle than the males, although release was within the optimal range of 31-36 degrees outlined by Young (2004).

The average horizontal release distance for the female throwers was 0.56cm. Four of the eight female throwers released the shot from behind the toe board. The greatest horizontal release distance recorded for the females was 23.03cm, with 13.69cm the next best distance. The average horizontal release distance reached by the elite female shot putters in Young and Li's (2005) study was 17cm with a range between -17cm and 39cm. The females in this study were well short of the horizontal release distance reached by elite female shot putters. The correlation analysis showed that this variable was positively correlated to throw distance for the females. The lack of horizontal release distance reached by the female athletes in this study is a flaw in their technique that needs to be improved by practice.

Horizontal release distance is directly affected by the distance the athlete is from the toe board. Many of the females did not make full use of the circle and as a result, the females were on average, 20cm away from the toe board. If all other positions remain the same, for every centimeter closer the females are to the toe board, the horizontal release distances increases and the throw distance increases by the same amount. Elite female rotators do an excellent job in minimizing their distance to the toe board, and some have their left foot in contact with the toe board as is seen with the 14th ranked female shot putter in the world (2nd best female rotational putter in the world) (Fig. 5-23). Young (2004) estimates that the distance the athlete is from the toe board contribute 2-3% to the final distance of the throw. Thus, minimizing this distance has a large effect on the success of the throw.

Fig. 5-23: An elite female rotational shot putter who has placed her left foot up against the toe board.

The males on the other hand, averaged a positive horizontal release distance of 15.27cm. When compared to the female mean, the males had a significantly greater horizontal release distance. A case can be made that the differences in limb length between males and females is one reason for this difference, however, in this case, poor female technique is more likely the cause for the large difference. All 10 of the male throwers released the shot in front of the toe board whereas only 4 out of the 8 females did. Therefore much of the difference observed between the males and females is due to the error in the female technique. The error made by the females that had a significant effect on the horizontal release distance was not getting close enough to the toe board. For the female throwers that do not get close enough to the toe board at release, they either need to make the adjustment in the first turn and increase the distance they travel across the circle in the airborne phase, or they need to start closer to the toe board and not at the posterior edge of the circle.

Distance from the toe board is only one factor that would have an effect on the horizontal release distance. Other factors that will have an effect on the horizontal release distance include: direction of the resultant force produced from the athlete's push off the shot circle,(which could be calculated by tracking the path of the athlete's centre of gravity throughout the second turn), and the amount of rotation that has occurred in the shoulders and the trunk flexion angle at release. In addition, the release angle will also affect the horizontal release distance. As the release angle increases, the horizontal distance the right arm can reach is decreased. The male athletes however had a significantly greater average release angle (35.7 degrees compared to 31.9 degrees of the females), and was found to be positively correlated to their distance thrown ($r=0.569$; $p = 0.0877$; Table 4-9). Elite female shot putters have been recorded to reach an average release angle of 35 degrees (Young & Li, 2005). Only one female in this study had a release angle of 35 degrees or more. Based on this finding, the greater the release angle, the greater the distance thrown. This would imply that the benefits of a greater release angle far outweigh the negative effects of the decreased horizontal distance. The minor decrease in the horizontal release distance as the result of a greater angle of release, therefore, is likely to be insignificant. Subsequently, it is unlikely the large difference in the horizontal release distance is due to the difference in release angle.

When comparing the release velocity means of the male and female groups, there was no significant difference found. The females averaged 10.16m/s and the males averaged 10.65m/s. Elite rotational shot putters have release velocities in excess of 13m/s (Luthanen et al., 1997; Linthorne, 2001; Ariel et al., 2004; Young, 2004). More specifically, Young and Li (2005) recorded release velocities of female shot putters to be between 11.9 and 13.2m/s whereas Ariel et al. (2004) calculated the male shot put medalists in Athens to have release velocities between 13.6m/s and 13.95m/s. Thus, the females and males in the study were both below elite standards, but even at the elite level; there is little difference between the top female release velocity and the top male release velocity. Therefore the significant difference in throw distance cannot be explained by the small difference in release velocity.

The correlation analysis also determined that release velocity was highly correlated to throw distance for both the males' and the females' (r=0.650 and r=0.646 respectively) (Tables 4-8 and 4-9), however the variable was only included in the regression equation for the prediction of the males throw distance, not the females. Release velocity of the females was removed from the regression equation by the statistics program during the stepwise process. It has been well documented that release velocity has a strong influence on throw distance (Dyson, 1973; Hay, 1993; Linthorne, 2001; M. Young, 2004), and the removal of this variable from the equation is likely due to its close relationship to several other variables that relate to release velocity in the same way that they relate to the throw distance.

The 21cm difference in release height between the males and the females was found to be significantly greater for the males. The males averaged a release height of 2.14m compared to the female average of 1.93m. Elite shot putters release the shot at a height of 220-235cm (Stepanek, 1989; Luhtanen et al., 1997; Coh & Stuhec 2005) and have an average standing height was 192cm (the top 20 male shot putters in the world). The average height of the males in this study was 189cm – only 3 cm less than the mean height of the elite male shot putters, yet their release height was approximately 6-21cm lower than ideal. This suggests that there was a lack of skill in the male subjects in this study. The females in this study averaged a height of 169cm compared to the mean of the top 20 female shot putters of 181.4cm. Based on a study of elite female shot putters by Young and Li (2005), the release height ranged from 192cm to 204cm with a mean of 197cm. Despite the 12.4cm difference in standing height, the females in this study averaged a release height only 4cm lower than the 197cm of the elite females. The females in this study were considered to have an excellent release height.

After release height was converted to release height relative to standing height, the females actually had better technique as they released the shot at 115% of their standing height and the males released the shot at 113% of their standing height. This supports the finding that the females in the study were more skilled in terms of maximizing their height of release. Therefore, much of the difference in throw distance cannot be explained by the difference in technique because the females had a better release height (after removing the anthropometrical difference in height between males and females).

The higher the shot is released from the ground, the more time the shot will be in the air ($t_{up} = Vv/g$), and the greater the time in the air, the greater the horizontal distance traveled by the shot, provided the horizontal velocity of the shot remains constant (d=vt). Whether skilled or not, the male subjects in the study released the shot 21cm higher than the females. "The height of release and amplitude of the shot acceleration are determined … primarily by body height and arm length" (Coh & Stuhec, 2005, p.58). It appears that the large difference in throw distance between males and females is mostly explained by the higher height of release and greater angle of release of the males in this study.

It was initially predicted that the male rotational shot putters would have greater flexion angles throughout the skill, as well as a greater step length and velocities. The results of this study did not support this hypothesis. Although the males had greater step lengths, the greater flexion angles and velocities varied between the genders throughout the skill.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

The rotational shot put technique is widely used by elite male shot putters; however, most elite female shot putters continue to use the glide technique, despite the rotational technique having several biomechanical advantages. The purpose of this study was to determine if the technique variables of the rotational shot put differed between males and females. This purpose was addressed by measuring key kinematic variables and statistically identifying difference in the performance of the rotational shot put technique by the two genders. It was hypothesized that the male rotational shot putters would have greater flexion angles, larger step lengths and greater velocities throughout the skill. An additional purpose of this study was to identify the key variables responsible for optimizing throw distance for each gender.

Data was collected from a total of 20 subjects on two separate occasions: the NCAA division II Track and Field Championships in Emporia Kansas, and at the University of Alberta, in Edmonton Alberta. Twelve males and 8 females participated in the study. With the exception of one former Canadian national champion, all of the athletes were at a similar level of development.

Over 40 kinematic variables related to throw technique were measured using the Dartfish 4.0.7 video analysis software. These variables included: trunk, hip, knee, and shoulder angles, as well as linear and angular distances and velocities. Furthermore, an overhead camera was used for 5 subjects to capture a transverse view of the rotational shot put technique to provide insight into the angular velocities of the shoulders and trunk that take place through each turn and key positions that occur throughout. The data enabled an analysis of many aspects of performance in terms of differences and similarities between the genders. Using t-tests, Pearson's Product-Moment Correlation and Forward Stepwise Multiple Regression analyses, numerous statistically significant differences between males and female rotational shot putters were found. Each of these analyses will be summarized individually. These athletes were not Olympic level throwers, but were collegiate level throwers of moderate skill level.

Backswing

None of the variables were significantly different during this phase of the skill between the males and females. From qualitative analysis, the males had a wider variety of backswings as some males did not have a backswing, some only used a partial backswing and others used a combination of high and low backswings. The females had a greater backswing range of motion, but they too showed variation in their backswing in terms of whether the high or low technique was used (half each). The differences in backswing may be a technique difference between males and females as the females may require a larger range of motion to build enough angular momentum to carry them through the rest of the throw.

First turn

Only one variable in the first turn was found to be significantly different statistically between the males and the females: the females hold the shot at a higher relative height than their male counterparts. This difference was a physiological difference rather than a technique error due to the differences in quadriceps strength between males and females.

Qualitative analysis of the film from the two groups found that the males have a greater tendency to rotate their shoulders ahead of their hips (they have a negative shoulder-hip separation) as they move into the first turn whereas the females had their hips and shoulders more square. In addition, the males tended to over-rotate before lifting the left foot. Analysis of the airborne phase determined that the men were more tilted and off balance while the females maintained a more vertical axis of rotation.

As the males finished their airborne phase, the right foot touch down was not consistent within the group as only 3 out of the 10 throwers landed in the middle of the circle. The females were more consistent as only 1 female landed away from of the centre line. The position of the right foot at touch down was not considered to be a gender difference, but rather a technique error of the male throwers in this study.

Second turn

A total of seven variables had significant differences between the male and female throwers. These seven variables included: left shoulder flexion and right knee flexion at second single support, the relative height of the shot's centre of gravity at second double support, maximal right hip and knee flexion during the second turn along with linear velocity of the shot through the power position and the angular velocity of knee extension during force production.

The females were found to have a greater amount of knee flexion at second single support than the males (a difference of 10.76 degrees). However, the males reached a greater maximum knee flexion angle shortly after the right foot touch down as the males measured a mean value of 66.07 degrees compared to 61.29 degrees for the females. Females also had greater flexion in their left shoulder at second single support, a greater hip flexion angle during the second turn, and a greater linear velocity of the shot through the power position. The males on the other hand had a much greater angular velocity in the right knee as they averaged a knee extensor angular velocity of 397.31 deg/s compared to the 317.34deg/s that the females reached.

Measurements taken with the overhead camera determined that the shoulder-hip separation of the female throwers was greater at second single support. However, the qualitative analysis of the other throwers yielded different results, which suggested that males had a greater shoulder-hip separation at second single-support. Further research is required before major conclusions can be drawn.

Release

The males averaged a mean throw distance of 16.92m compared to the females who averaged a mean throw distance of 13.90m with a shot approximately half the weight. The 3.02m difference was found to be statistically significant. The release velocity, however, showed no significant difference between the genders as the males averaged 10.65m/s compared to the females' average of 10.16m.

Horizontal release distance and the release angle both proved to be significantly different from one gender to the other. The males had a greater release angle of 35.70 degrees compared to the smaller 31.90 degrees of the females. In addition, the male throwers had a much better horizontal release distance than the females. It was determined that only 4 of the 8 females released the shot in front of the toe board compared to the males who all released the shot in front of the toe board.

Overall, the results of this study were not as predicted. Males were expected to have greater knee, hip and trunk flexion angles throughout the skill. In addition, it was also predicted that males would have a greater "step" length across the circle and greater linear and angular velocities of the shot. It was determined that the female rotational shot putters had greater knee, hip and trunk flexion angles at various phases in the skill, as well as greater average linear velocities of the shot. Therefore, the males and females proved to have different strengths and weaknesses in their techniques than first predicted.

KINEMATIC RELATIONSHIPS WITH THROW DISTANCE

All THE kinematic variables were correlated with throw distance to determine which kinematic variables had a significant relationship with the throw distance.

Female rotational shot put

The results showed 8 variables that had correlation coefficients greater than $r=0.5$. Statistically, however, only 4 of these variables were significantly correlated at $p \leq 0.05$. Trunk flexion at maximum backswing and the relative height of the shot's centre of gravity at first single support were both negatively correlated to throw distance (-0.771 and -0.678 respectively). The right shoulder abduction angle at the point when maximum right knee angle was reached had a strong positive relationship to throw distance as did the velocity of release.

Male rotational shot put

Correlation analysis of the male data determined the release angle and release velocity showed the strongest relationship to throw distance and both were found to be statistically significant. The release velocity yielded the highest correlation of 0.602 with throw distance and the release angle having a correlation coefficient of 0.569 with throw distance.

STEPWISE MULTIPLE REGRESSION ANALYSIS

A forward stepwise multiple regression analysis was used to determine the most important variables responsible for predicting maximal throw distance. The regression analysis was conducted separately for the males and females.

Female rotational shot put

The prediction equation to predict female throw distance included five key variables that explained 100% of the throw distance. These variables included: right knee angle at the power position; maximum right knee flexion during the second turn; right knee flexion at second single support; right hip abduction during leg sweep and trunk flexion at maximum backswing. It is important to point out that neither release angle or release velocity were predictors of throw distance.

Male rotational shot put

The same statistical analysis of the male subject data set identified 7 variables found to be of greatest importance to vertical velocity. These 7 variables (listed in order of importance) were: relative height of the shot's centre of gravity at the beginning of second single support; release velocity; angle of the trunk to the right of vertical at leg sweep; maximal right hip flexion during the second turn; right shoulder abduction at first single support; right knee angle at power position and width of the base of support at the second double support phase. These 7 variables explained 99% of the variation in throw distance.

CONCLUSIONS

Based on the findings of the study, the following conclusions appear to be justified based on statistical analysis:

1. Males in this study had greater throw distances than females at this level of development, using a shot approximately two times heavier. Note that there is a difference of 0.48m between the male and female shot put world records.
2. The females hold the shot at a greater relative vertical distance above the ground at all phases of the skill than the males, with the exception of the second single-support phase
3. Females extend their knee as they move into first single support, compared to most of the males who were able to maintain the same knee flexion used during the first double-support.
4. Females have a greater maximum hip flexion angle than males in the second turn.
5. Males have a higher angular velocity in their right knee through the power position.
6. Females do not release the shot close enough to the toe board which significantly reduced their throw distance.
7. Males released the shot at a greater release angle than the females which contributes to the shot remaining in the air longer and ultimately traveling further than the females' throws.
8. Females in this study had a better release height than the males in this study when factoring out the differences in height.

Based on the findings of the study, the following conclusions appear to be justified based on repeated observation of video data:

1. Females have larger range of motion during the backswing phase.
2. Males at this level of development have a tendency to rush the first turn (lead the first turn with their shoulders), creating a negative shoulder-hip separation at take-off leading to an unbalanced position at second single-support.
3. Females use a more vertical axis of rotation in the first turn than males which leads to a more balanced position at second single-support.
4. Female are better positioned relative to the centre line of the shot circle, and they are better balanced than males.

RECOMMENDATIONS

The following recommendations are suggested for future studies on the rotational shot put technique of males and females:

1. Since one of the goals of the first turn is to place the body in the best possible position for the second turn, future studies should examine the relationship of the second turn variables only to throw distance. In this study, the interrelationships between some of the first turn and second turn variables eliminated some of the important second turn variables from the regression equations.
2. Another study should examine the relationship of first turn variables with the second turn variables that are of significance to throw distance. This will help determine the effect of errors made in the first turn to positions reached in the second turn.
3. An investigation of the timing of knee, hip and trunk extension in the second turn would help better understand the proper sequencing of these movements and their effect on throw distance.
4. Researchers should examine the relationship between the variables of the backswing and the variables of the first turn.
5. Further breakdown of the angular velocities and accelerations of the shot through the various phases of the female rotational shot put skill should be performed. For example, angular velocity of the shot from maximum backswing to first single-support, from first single support to takeoff, angular velocity of the shot through the airborne phase, immediately after right foot touchdown, from second single-support to second double support and from second double-support to release.

6. More camera angles should be used to collect more data on variables that could not be captured with the ones used in this study. For example, the overhead camera used in this study was used to capture the rotation of the shoulders and hips. However, several times throughout the skill the athlete has a flexed or laterally flexed trunk and the line of the shoulders is sometimes unclear. For this reason, another camera should be situated on an oblique angle looking down at the skill to try to capture trunk rotation when the athlete is in a position of trunk flexion
7. A study designed to look at the possible gender technique differences should be conducted during competition.
8. Future studies comparing male and female rotational shot put technique should measure more anthropometric measurements including arm and leg lengths. This will help calculate horizontal release distance in relation to limb length.
9. Flexibility tests of shot putters should be conducted to determine if poor shoulder-hip separations are due to poor technique or due to poor flexibility and if there are any significant differences between males and females.
10. More studies analyzing the timing of each of the phases of the rotational shot put technique should be conducted and look at possible temporal pattern differences between elite and sub-elite rotational shot putters as well as differences between males and females.
11. Studies examining what the effect of increasing the knee angle after second single support has to throw distance, and what range of knee flexion is ideal.
12. More studies should look into the importance of the left arm and its contribution to angular velocity of the trunk.

13. More efforts should be made to quantitatively analyze the rotational shot put technique performed by females competing at the international level.
14. Further studies need to include more subjects to ensure significant results and better generalization to a wider range of subjects.
15. Technique differences between males and females should be analyzed by comparing the technique of males and females who throw the same distance.

COACHING RECOMMENDATIONS

The rotational shot put technique is close to dominating the sport in men's competition and the technique is now showing strength in women's competition as more female rotational shot putters are having success at the international level. Considering the wide variety of rotational shot put techniques that are used by today's shot putters, some coaching recommendations are made to help incorporate the significant findings of this study:

1. Males at this skill level should consider using a larger backswing to develop a greater stretch in their trunk and use the increased range of motion to generate more angular velocity and momentum before takeoff in the first turn. With a greater angular velocity before takeoff, the temptation to speed up the turn should be minimized and the male throwers may not try to rush the turn and lead with their shoulders at takeoff.
2. Males should use a more vertical axis of rotation in the first turn to help them be in a more balanced position at second single-support. The position of the athlete at second single-support is very important to the success of the throw and this is one area in which the male subjects in this study were very unskilled.

3. Females should work on their leg strength to allow them to maintain a lower position during the first single-support phase as knee flexion angle at this phase of the skill was negatively correlated to throw distance. More specifically, females should incorporate more strength training in their right quadriceps, right hip abductor, and right hip flexor groups to help increase their knee and hip flexion angles throughout the throw. By keeping a lower position at first single-support, the throwers will increase their chances of keeping their airborne phase low to the shot circle and provide themselves a better opportunity to begin the second single-support phase from a lower position. This would allow them to maximize the range of motion the shot can move through in the power position. Additional forces can be applied to the shot and also influence the movement trajectory of the shot through the power position which can help increase the angle of release. An increased angle of release would increase the vertical component of the release velocity and lead to an increased time in air of the shot which leads to an increased distance thrown.
4. According to Coh and Stuhec (2005), the final movements of the rotational shot put skill are generated by the arm and hand. Females should focus on using their legs to generate more angular velocity and momentum moving into the second turn to compensate for having a much weaker upper body than males. In other words, because the females are relatively weaker in the upper body, they cannot count on their right arm to contribute as much force to the shot as their male counterparts. Therefore, generating a greater linear velocity on the shot through the second turn should be emphasized as angular velocity directly translates into linear velocity at release as $V=r\omega$.

5. Females should work on creating a better shoulder-hip separation at second single-support as this has been positively correlated to throw distances in many studies. The greater the shoulder-hip separation, the greater the stretch in the trunk muscles and the more elastic energy stored in these muscles. As a result, this stored energy is released when these muscles concentrically contract and a greater angular velocity about the longitudinal axis through the trunk is created. When the shoulders stop rotating, this angular velocity is eventually transferred to the shot which can result in a greater release velocity of the shot.
6. Females who plant their left foot well behind the toe board should not start from the posterior edge of the circle but from a position closer to the midline of the circle in order to maximize the horizontal release distance. This was one area in which the female throwers in this study lost considerable distance in their throw.

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APPENDIX A

ETHICS APPROVAL

APPENDIX B

INFORMED CONSENT FORMS

Guidelines for Informed Consent

Research Project Title: A Biomechanical Comparison of the Rotational Shot Put Technique Used by Males and Females
Approach: How male and female rotational shot putters differ in technique
Researcher(s): Carolyn Taylor B.E.S.S. and Advisor: Dr. Marion J.L. Alexander, professor, Faculty of Physical Education and Recreation Studies

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Outline of the Study:

There are two main purposes of this study: to examine the techniques of male and female rotational shot putters, in order to assist coaches and athletes in improving rotational shot put techniques; and to provide data that will be used in a master's thesis study focusing on the biomechanical differences between the rotational shot put technique used by males and females. Hopefully from this study, female shot putters will adapt easier to using the rotational shot put technique and coaching implications can be made.

Methodology:

You will be filmed on one occasion only, while practicing at Francis G. Welch Stadium, using filming equipment from the Biomechanics Laboratory in the University of Manitoba. All practices are organized and administered by the coach, who will instruct you regarding the skills to perform. Prior to filming you, the filming procedures will be explained. You will be asked to perform the skills as you normally would in a competitive situation, and your techniques will be filmed. You must provide informed consent for the study prior to filming. All filming procedures will be organized and administered by the principal investigator, Carolyn Taylor and Dr. Marion Alexander, who will be assisted by a qualified graduate student.

Three video cameras will be used to film the athletes along with a frame to support an overhead camera. One camera will be placed directly above the shot put circle to capture an overhead view, one camera will be placed to the side of the athlete and another placed to the rear of the shot put circle. All cameras will be placed at a safe distance from the athlete and will not interfere with the performance. The coach will instruct you regarding which skills are to be performed while the cameras are filming. The cameras will continue to film you until all of the skills of interest have been performed

When filming is completed, the videos will be analyzed by the principal investigator. The types and ranges of motion in each of the skills, as well as selected linear and angular velocities in each of the skills will be described. Each athlete will receive a copy of their videos the following day in the form of a compact disc. It is possible that some of the technique descriptions developed from this analysis may eventually be published in a technical journal in the sport being examined.

Risk:

There is no additional risk involved in this study, as you will perform the skills as you would normally perform them in a practice situation. The cameras will be out of the way, and will not interfere in any way with your performance of the skills.

Confidentiality:

The video will be viewed only by the researchers involved in the study and the athlete and the athlete's coach. The data derived from the video will be available to the coaches and athletes in order to help to improve performance. No one will have access to the video or data except the principal investigator and the research assistants. It is possible that the technique analysis data will be published in a technical journal, however the identity of all subjects in the study will be kept confidential.

Signature:

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Principal Researcher: Carolyn Taylor B.E.S.S., graduate student at the University of Manitoba. Advisor Marion J.L. Alexander, Professor, Faculty of Physical Education and Recreation Studies, Ph 474 8642

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122. A copy of this consent form has been given to you to keep for your records and reference.

______________________	______________________	__________
Participant's name (print)	Signature	Date
______________________	______________________	__________
Researcher and/or Delegate	**Signature**	**Date**

APPENDIX C

PILOT STUDY

PILOT STUDY

Introduction

The primary purpose of this pilot study was to identify any key differences between the rotational shot put technique used by men and the rotational shot put technique used by women that could be considered in this study. A sub-purpose of this study was to test the overhead camera apparatus that was designed specifically for the biomechanics lab at the University of Manitoba and to determine if the footage taken by the camera located on this frame would be a benefit to this study.

METHODS

Subjects

The pilot study was conducted at the Max Bell field house at the University of Manitoba on February 4th, 2006. One male and two females were video taped for this study and all signed informed consent forms (see Appendix) prior to video taping which falls under Dr. Alexander's blanket consent. The male and two of the female subjects are university students ranging in age from 19-24 years of age and have thrown rotational shot put for over two years and currently compete on behalf of their university. The three athletes were in peak form as they have been competing indoors all season and were in Winnipeg in order to compete in the Cargill games track meet the following day.

Filming technique

Three cameras were used for filming – two Canon GL2 cameras along with one canon Optura 200MC. The Canon Optura 200MC being the smaller of the three cameras, was situated on the overhead camera frame approximately four metres from the surface of the shot circle in order to capture the transverse view of the rotational shot put. Using a 70 foot 4 pin to 4 pin firewire cable, the Canon Optura 200MC was connected to a Toshiba Satellite JM8 laptop computer and the video was directly imported using Dartfish 4.0.7 Import mode. The Canon GL2 cameras were setup on tripods, 90-degrees to each other and approximately 4 meters away from the centre of the shot circle. One

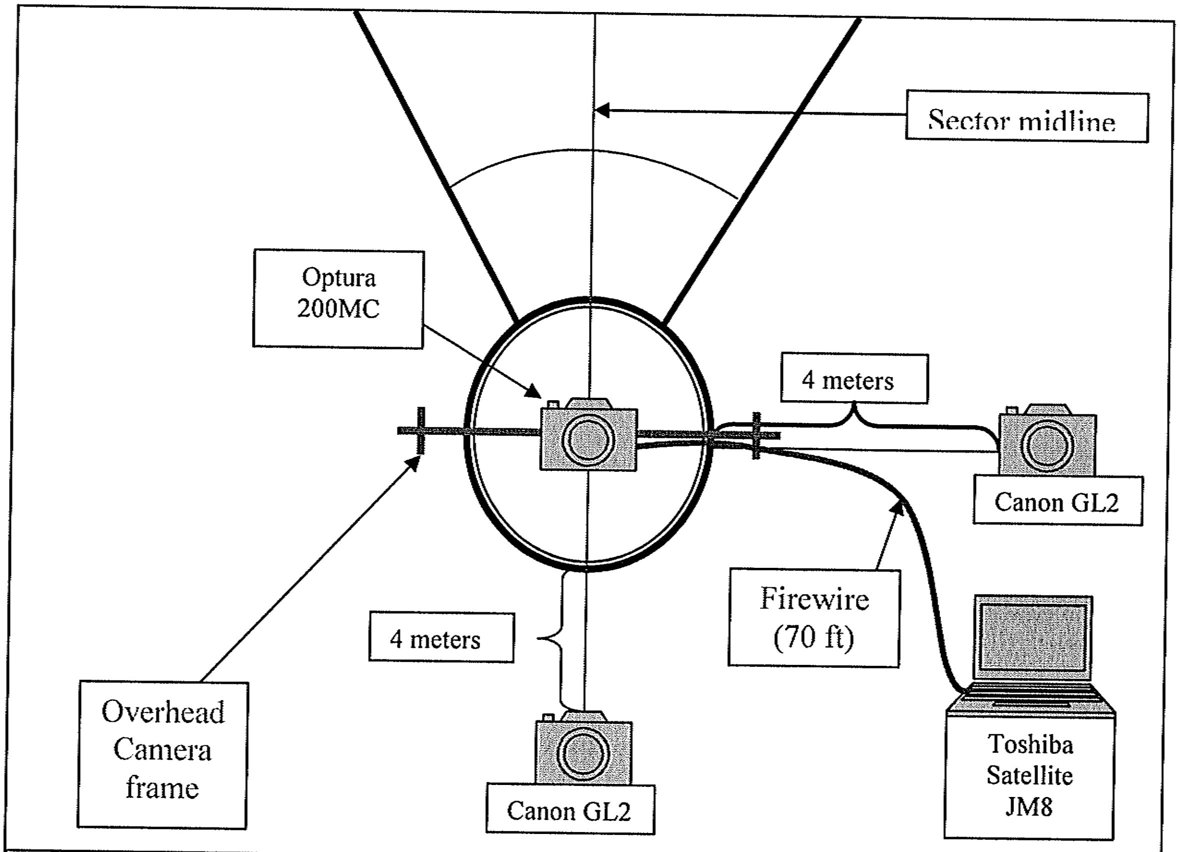


Fig. C-1: Pilot Study Camera positioning.

camera was setup to the right of the circle to capture the sagittal view of the throwing circle and the other camera was setup with the midline of the shot circle and throwing sector to capture the posterior view of the throwing circle. All of the athletes were right handed so the cameras remained in the same position with the same settings for all throws. All cameras had a shutter speed of 1/500 of a second and were recording onto

Fuji 60 minute mini-DV tapes for the full duration of the video taping session to ensure that no portions of the throws were missed.

Warm-up

The three university athletes that were filmed for this study competed in the 2006 Cargill Games the following day. As a result, the filming session occurred during one of their scheduled practice periods. Subsequently, the coach conducted the warm-up with the athletes which consisted of a light jog, stretching, weight throwing and various drills using lighter weight shots before moving up to their standard weight shots (4kg for the women and 7.26 for the male athlete). This was the same warm-up used by each of the athletes the following day prior to the competition. Following the warm-up, each athlete took a five minute break before they each threw six throws that were video taped for analysis.

Filming protocol

After informed consent forms were signed, all the athletes underwent their regular warm-up throws. Following warm-up, the athletes were instructed to throw as they would in competition – in other words, throw as far they can. In addition to the four subjects that were video taped for the purpose of this study, there was one additional thrower who uses the traditional glide technique who was also video taped. The extra thrower made the rest period between throws more similar to the rest between throws in competition. The additional thrower was welcomed.

Each throw was marked with a piece of masking tape that recorded the thrower and throw number on each piece. Each shot putter threw a total of six throws and the top three throws (farthest throws) were measured following the video tapping session after the athletes had left.

Digital Video Analysis

Qualitative and quantitative analysis was conducted using the Dartfish TeamPro 4.0.7 software. The video taken by the overhead camera was all imported into the Toshiba Satellite JM8 laptop computer live using Dartfish's In the Action. The remaining video was entered into the computer using Dartfish's Import feature following the conclusion of the filming session.

Upon review of the top three throws from each participant, the best throw from each of the athletes was determined to be the farthest throw from each athlete. In addition to having the farthest horizontal distance, these throws were all legal throws with neither one of the athletes stepping out of the circle prematurely, and there were no irregular changes in form from the other five throws for each athlete. These three throws (the best from each athlete) were analyzed using Dartfish's Analyzer mode using the angle tool, measurement tool, data table, split screen mode, overlay mode and timeline. Quantitative data was collected by measuring the following variables:

Phase of the skill	Variable(s) measured
Start position	▪ Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle ▪ Angle formed between the line of the hips and the midline of the circle ▪ Left knee flexion ▪ Trunk flexion ▪ Left hip flexion ▪ Height of centre of gravity of the shot ▪ Left shoulder abduction ▪ Width of base of support

Phase of the skill	Variable(s) measured
Maximum backswing	▪ Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle ▪ Angle formed between the line of the hips and the midline of the circle ▪ Shoulder-hip separation angle ▪ Left knee flexion ▪ Trunk flexion ▪ Left hip flexion ▪ Height of the centre of gravity of the shot ▪ Left shoulder flexion
First turn	▪ Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (FSS) ▪ Angle formed between the line of the hips and the line perpendicular to the midline of the circle (FSS) ▪ Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (SSS) ▪ Angle formed between the line of the hips and the line perpendicular to the midline of the circle (SSS) ▪ First turn average angular velocity of the hips ▪ First turn average angular velocity of the shoulders ▪ Shoulder-hip separation (SSS) ▪ First turn angular velocity of the shot ▪ Horizontal linear velocity of the shot through the first turn ▪ Right shoulder abduction ▪ Right hip abduction during leg sweep ▪ Lateral trunk flexion during leg sweep (to the right) ▪ Length of "step" into the centre of the circle ▪ Height of shot's centre of gravity at single support ▪ Height of shot's centre of gravity at take-off ▪ Height of shot's centre of gravity at peak height of airborne phase ▪ Right hip extension at single-support ▪ Extension of left knee at take-off ▪ Right hip abduction during leg sweep ▪ Lateral trunk flexion at leg sweep ▪ Left knee flexion at single support ▪ Angle formed between the line from the left toe and left hip with the vertical (lean into the circle) during the right leg sweep

Phase of the skill	Variable(s) measured
Second turn	▪ Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (SDS) ▪ Angle formed between the line of the hips and the line perpendicular to the midline of the circle (SDS) ▪ Second turn average angular velocity of the hips ▪ Second turn average angular velocity of the shoulders ▪ Modified second turn angular velocity of the shoulders ▪ Modified angular velocity from SDS-REL ▪ Horizontal linear velocity of the shot through the power position (SDS-REL) ▪ Horizontal linear velocity of the shot through the second turn ▪ Shoulder-hip separation (SDS) ▪ Right shoulder flexion at max. right knee during single-support ▪ Trunk flexion at maximum right knee flexion during 2nd single-support ▪ Maximal right hip flexion during second turn ▪ Lateral trunk flexion at power position ▪ Maximum right knee flexion during second turn ▪ Width of base of support at 2^{nd} double support ▪ Height of shot's centre of gravity at 2^{nd} single support ▪ Height of shot's centre of gravity at the beginning of double support ▪ Right knee flexion at right foot touch down ▪ Trunk flexion at right foot touchdown ▪ Left shoulder flexion at right foot touch down ▪ Right knee angle at power position
Release	▪ Angular velocity of the right horizontal shoulder adduction ▪ Horizontal release distance ▪ Angle formed between the line of the hips and the line perpendicular to the midline of the circle ▪ Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle ▪ Shoulder-hip separation (REL) ▪ Distance of left toe from toe board ▪ Angular velocity of the right elbow at release ▪ Angular velocity of the right wrist at release ▪ Right knee angular velocity during force production ▪ Release height ▪ Release angle ▪ Release velocity

RESULTS

Analyzing the data collected for the male and two female shot putters, there are many similarities and also many differences. Some of the differences between the male and two female shot putters suggest that the females perform the rotational technique better than the male subject however there are key variables in which the male shot putter has stronger numbers.

First and foremost, the throw distance is the most important variable, and is also the variable that varies the most between the genders. The male subject put the shot 15.05m whereas the two females put the shot 13.05m and 13.74m (an average of 13.40m) - a difference of 1.65m. The male shot putter also released the shot 1.09m/s faster than the females' average release velocity of 8.64m/s as he released the shot with 9.72m/s linear velocity (see Table C-1).

Table C-1: Key variables for each athlete are provided along with the combined average for the two females to allow for easier gender comparison. The calculated difference between the genders is provided in the last column.

Variable (units)	F-1	F-2	F-Average	M-1	Difference (M-1 – F-average)
Release height (m)	1.92	1.90	1.91	2.20	0.29
Release angle (degrees)	34.80	35.60	35.20	34.40	-0.80
Release velocity (m/s)	8.10	9.17	8.64	9.72	1.09
Horizontal release distance (m)	-0.61	-0.03	-0.32	0.04	0.36
Throw Distance (m)	**13.74**	**13.05**	**13.40**	**15.05**	**1.65**

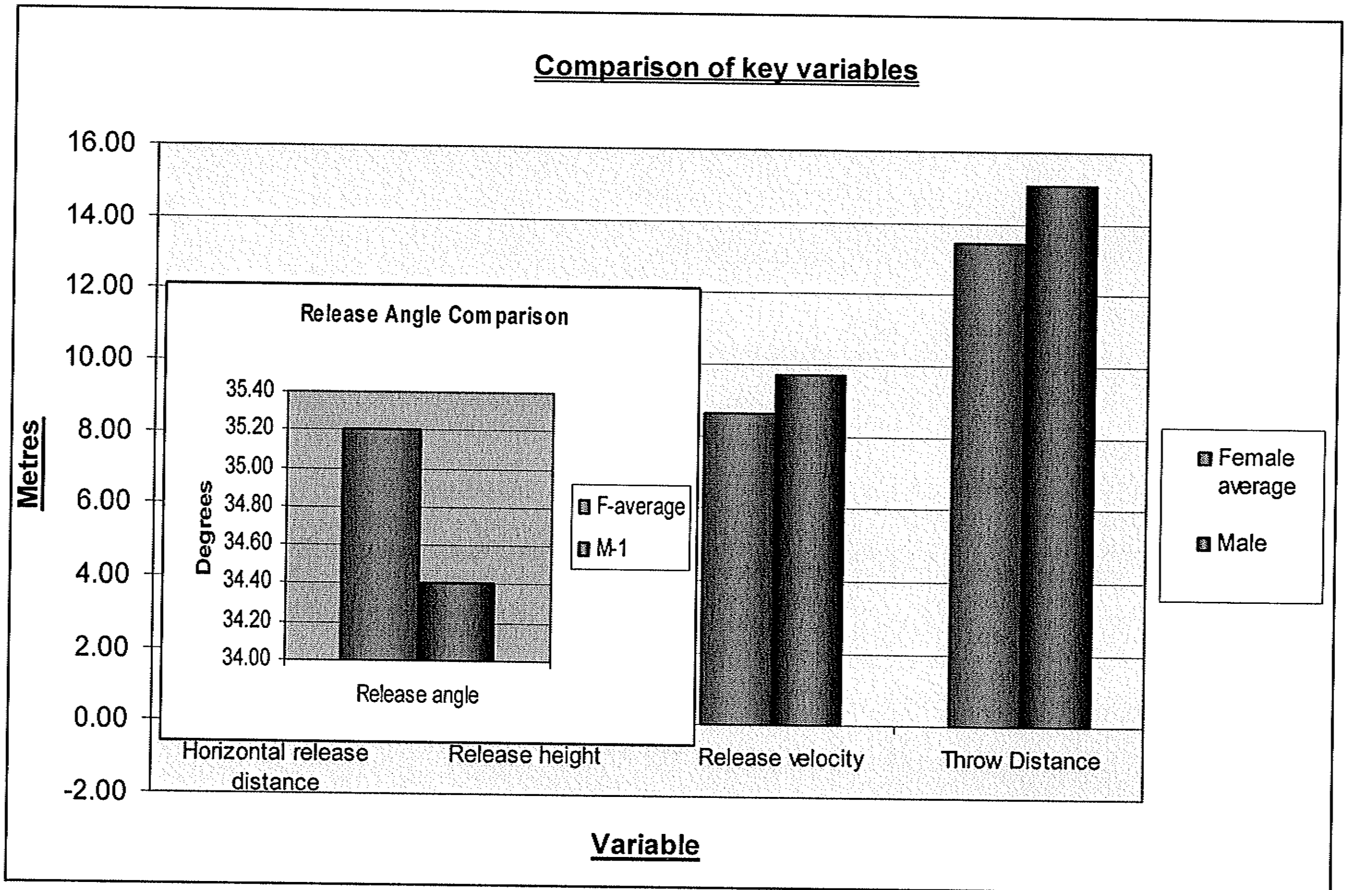


Fig. C-2: Fig. highlighting the gender differences in five key variables: Horizontal release distance; release height; release velocity; throw distance and release angle.

The horizontal release distance for the one male subject was 0.04m indicating that the male shot putter released the shot in front of the toe board, adding an additional 4cm onto his throw distance. The average for the females' horizontal release distance was -0.32m. As a result, 36cm of the difference in measured throw distance between the male and females can be explained by the difference in the horizontal release distance. Related to the horizontal release distance is the between the shot putter's front toe with the inside edge of the toe board. On average, the females' toes were a distance of 34.6cm from the front inside edge of the toe board whereas the male shot putter was a distance of 12cm from the toe board.

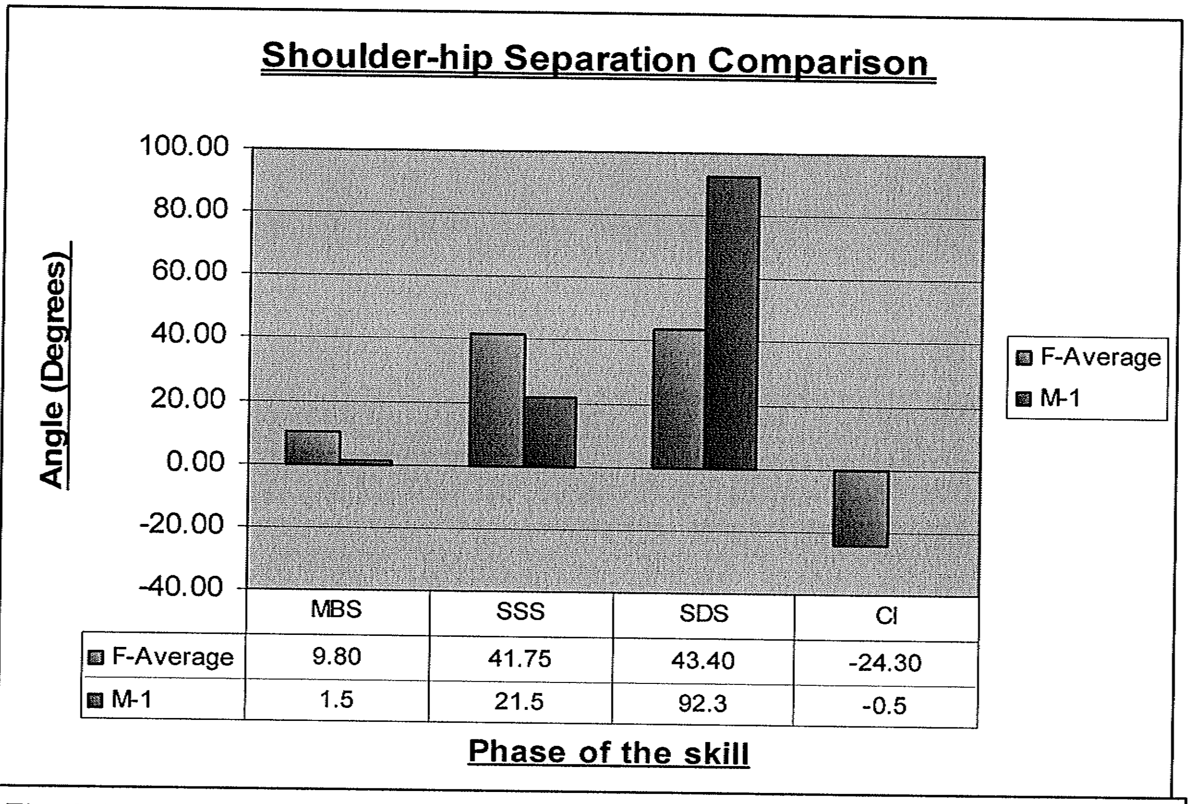
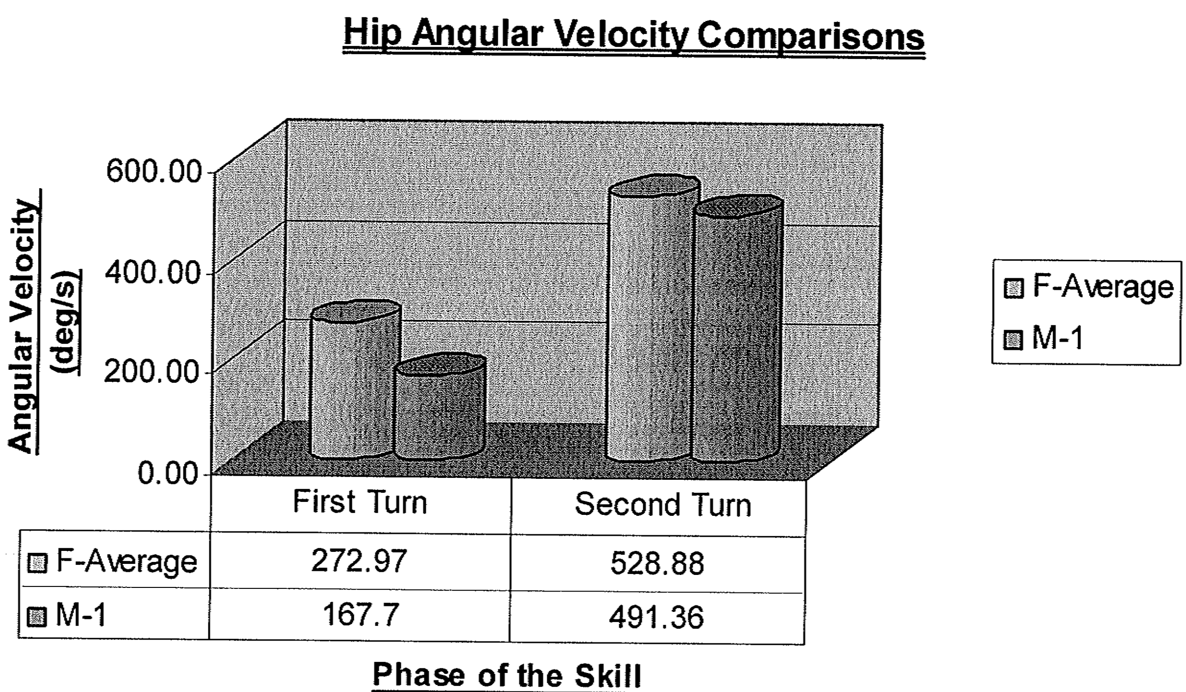


Fig. C-3: Comparison of shoulder-hip separation between the male shot putter (M-1) and the average of the two female shot putters (F-Average) throughout (MBS) Maximum backswing, (SSS) Second single-support, (SDS) Second double-support and (CI) Critical Instant.

Another variable that showed significant differences between the two genders was the shoulder-hip separation. In terms of the shoulder-hip separation throughout the skill the females were able to create a better shoulder-hip separation during the early phases of the skill however the male athlete had a much better shoulder-hip separation near the end of the skill (see Fig. C-1). At maximum backswing, the female shot putters averaged a shoulder hip separation of 9.8 degrees as opposed to the 1.5 degrees that the male created. Comparing the shoulder-hip separation at the end of the first turn at second single support, the females are able to maintain a greater shoulder-hip separation with 41.75-degrees of separation compared to the male's 21.50-degrees of separation.

At second double-support however, the male athlete created a much superior shoulder-hip separation 92.3-degrees as opposed to the females' average of 43.4-degrees. In addition, the male shot putter had less shoulder-hip separation than the females at critical instant. The male shot putter had a shoulder hip separation of -0.5 (shoulders were ahead of the hips) whereas the females had an average shoulder-hip separation of -24.3-degrees (see Fig. C-3 above).

It must also be noted the difference in the first turn velocities between all three subjects. The females rotated their hips more quickly through the first and second turns than the male subject did (see Fig. C-4). Upon further analysis of the hip velocities, the male subject had a greater increase in his hip velocity from turn one to turn two (increase of 323.66-deg/s) as opposed to the females who had an average increase of 255.91-deg/s.



	First Turn	Second Turn
F-Average	272.97	528.88
M-1	167.7	491.36

Fig. C-4: Comparison of angular velocity of the hips between the genders. F-Average (Average value calculated for the females), M-1 (Male subject).

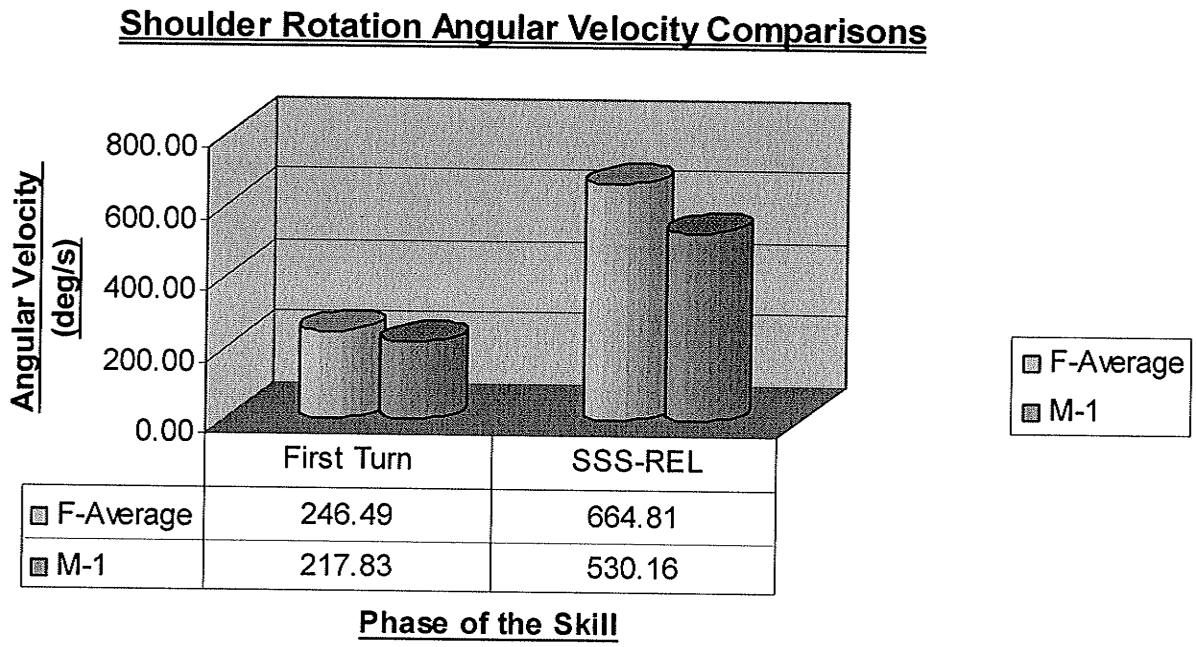


Fig. C-5: Comparison of the angular velocity of shoulder rotation between the genders. F-Average (Average value calculated for the females); M-1 (Male subject); SSS (Second single-support); REL (release).

When analyzing the angular velocities of the rotation of the shoulders, the females once again had greater angular velocities throughout the throw (see Fig. C-3). During the first turn, the females averaged an angular velocity of 246.49 deg/s while their male counterpart had a first turn shoulder angular velocity of 217.83 deg/s – a difference of 28.66 deg/s. The second turn angular velocities of the shoulder girdle showed a more drastic difference (134.65 deg/s) as the females averaged an angular velocity of 664.81 deg/s compared to 530.16 deg/s that was calculated for the male subject in this study. The calculated angular velocities of shoulder rotation during various key phases of the rotational shot put for each subject that participated in the pilot study are listed in Table C-2.

Table C-2: Calculated average angular velocities (deg/s) for critical intervals of the skill.

Phase of the skill	F-1	F-2	M-1	F-average	Difference (M-1 – F-average)
Double Support (MBS-FSS)	132.53	142.46	129.03	137.50	-8.47
Single Support (FSS-LFTO)	351.39	213.64	287.81	282.52	5.29
Airborne (LFTO-SSS)	433.33	246.99	0	93.17	-93.17
First Turn (MBS-SSS)	265.31	227.66	217.83	246.49	-28.66
Second Single Support (SSS-SDS)	447.57	490.00	275.08	468.78	-193.7
To Release (SDS-REL)	1053.50	820.40	767.60	936.95	-169.35
Second Turn (SSS-REL)	707.07	622.55	530.16	664.81	-134.65
Modified Second Turn (SSS-PTM)	638.44	609.32	525.88	623.88	-98.00
Modified to Release (SDS-PTM)	1004.79	804.92	1004.82	904.85	99.97

The measured right knee flexion angle at right foot touchdown for the females averaged 47.3-degrees compared to 82-degrees of flexion in the male subject's right knee (refer to Fig. C-7). The 34.7-degrees difference is substantial amount considering the importance of the right knee in terms of force generation (see discussion). Moreover, the knee flexion is of continued importance as the athlete moves to the power position. At this point in the skill, the male had 63 degrees of flexion in his right knee and the females' averaged 53.45 degrees of flexion (refer to Fig. C-6).

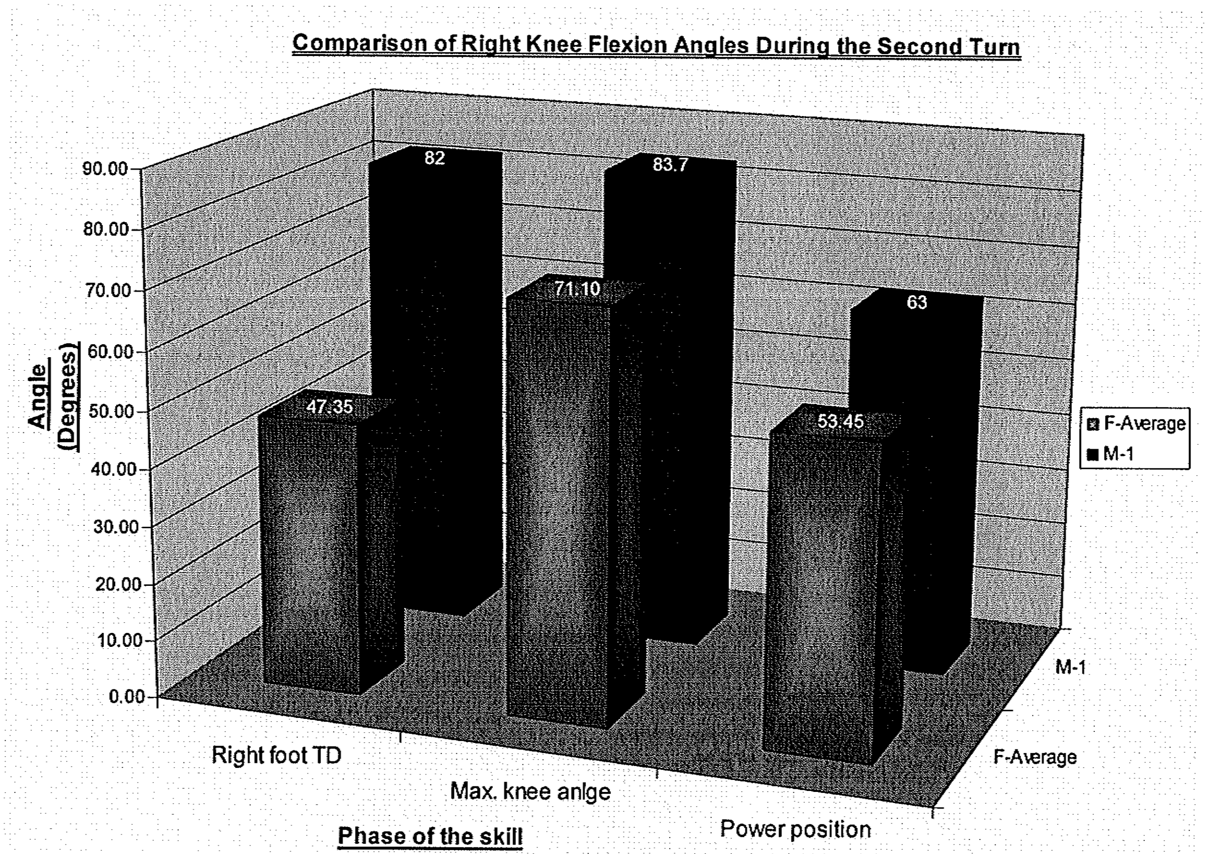


Fig. C-6: Graph comparing the knee flexion angles through three phases of the rotational shot put skill between the females' average angles (F-average) and the male subject in the study (M-1). Right foot touchdown (Right foot TD), Maximum knee angle observed during the second turn (Max. knee angle) and the Power position (second double-support).

In terms of range of motion, hip flexion angles and lateral trunk flexion angles are also important. For both variables, the male participant in the study had values greater than the females. The male had a maximum hip flexion angle of 69.9 degrees and a maximal value of 21.8 degrees of lateral trunk flexion. The females on the other hand averaged a maximal hip flexion angle of 64.60 degrees and a maximal lateral trunk flexion angle of 11.70. The values for the males and females (average) are displayed in Fig. C-7.

The linear velocity of the shot through each phase of the skill – most notably, the first turn, second turn and power position also showed considerable differences between the genders. During the first turn the females averaged a linear velocity of the shot of 1.12 m/s whereas the male shot putter has a linear velocity of 1.2 m/s (0.08m/s faster than that of the females) (see Table C-3). The other notable difference in the linear velocities

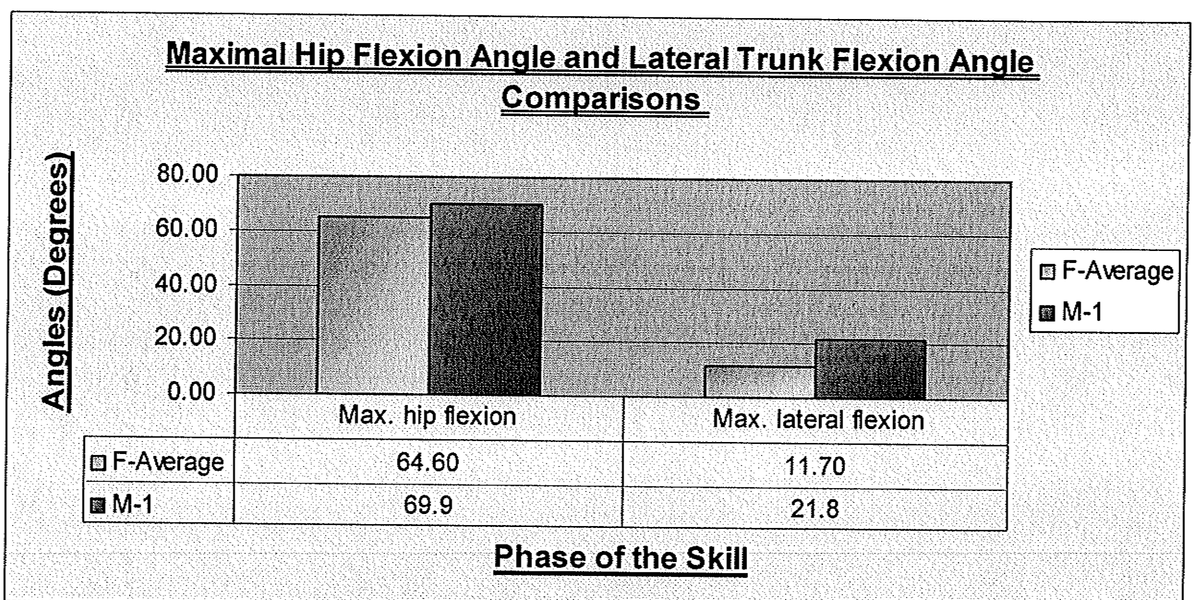


Fig. C-7: Average maximum hip flexion angle (Max. hip flexion) for females compared to the male subject (M-1) and the maximum lateral trunk flexion angles (Max. lateral flexion) for each gender. Values for each variable are provided in the table below the graph.

of the shot is the average linear velocity of the shot from the second single-support phase (SSS) to the release of the shot (REL) (a difference of 0.47 m/s) (see Table C-3). The linear velocities for each of the subjects are provided in Table C-3.

Table C-3: The linear velocity of the shot through the phases of the rotational shot put skill are provided for each subject used in the study as well as the females' average linear velocity of the shot through these same phases. The differences between the male and average female linear shot velocity was calculated by subtracting the average female linear velocity from the calculated linear velocity of the male's shot.

Phase of the skill	F-1	F-2	F-Average	M-1	Difference
Linear velocity of the shot through the first turn (FSS-SSS)	1.42 m/s	0.82 m/s	1.12 m/s	1.2 m/s	0.08 m/s
Linear velocity of the shot through second turn (SSS-SDS)	0.92 m/s	0.82 m/s	0.84 m/s	0.97 m/s	0.13 m/s
Linear velocity of the shot through the power position (SDS-REL)	5.28 m/s	5.90 m/s	5.59 m/s	5.76 m/s	0.17 m/s
Average linear velocity of the shot from SSS-REL	2.5 m/s	2.57 m/s	2.54 m/s	3.00 m/s	0.47 m/s

DISCUSSION

Footage taken with the overhead camera proved to be very valuable as the measurement of shoulder-hip separation for each athlete would not have been possible without the transverse view. As it turned out, shoulder-hip separation was one variable throughout the rotational shot put skill in which there were obvious gender differences. During some phases of the skill, the females had better shoulder-hip separation and at other times, the measurements favored the male subject.

The shoulder-hip separation is an important variable to the success of the throw (Bartonietz, 1994; Hay, 1993; M. Young, 2004). The reason for this is because the greater the shoulder-hip separation in which the shoulders are rotated further back than the hips, the greater the trunk muscles will be stretched on the shot putter's body which will initiate the stretch reflex in the necessary muscles that will be used for force production which will help the athlete rotate the upper-body more efficiently.

The male athlete in this study was able to maintain a shoulder-hip separation of 48.9 degrees more than the average shoulder-hip separation of the two female subjects. Thus, the male athlete was able to develop a greater stretch in his trunk rotator muscles at the second double-support phase of the skill – the beginning of the power position and he also leaves himself with a much greater range of motion to apply force to the shot as he contracts his trunk muscles.

Furthermore, the male shot putter had his shoulders much more square to the throw as well as, and partly due to a minimal shoulder-hip separation at release. This suggests that the male shot putter had a more effective hip block as he significantly slowed down his hip rotation and allowed his shoulders to catch-up to his hips. This allowed for the angular momentum he generated with his legs and hips to be transferred to his trunk and ultimately his shoulders (Hay, 1993). According to the literature, less shoulder-hip separation at release was a strong predictor of a greater measured throw distance (M. Young, Li, L., 2005). In the case of the females, the shoulders were over rotated at release and did not provide an efficient base for the final force producing movements of horizontal shoulder adduction, elbow extension and wrist flexion to occur as the athletes' trunk rotation continued past the forward facing position. The gender differences in the degree of shoulder-hip separation at critical moments of the skill warrant closer examination with more subjects.

Aside from the shoulder-hip separation differences, other variables also showed a significant amount of variation between genders. Among these variables were right knee flexion angles, hip and trunk flexion angles and the release parameters: release angle, release height and release velocity. While arguments can be made that the differences in technique lie in the different anthropometric measurements between males and females – many of these variable cannot.

There are three main variables that determine the horizontal distance of a projectile; release velocity, release angle and release height (Hay, 1993). At first glance, the male shot putter appears to have better results in two of the three key parameters that determine the horizontal distance of the throw – release height and release velocity. However, when the standing height of each athlete was factored into the release height of the shot to find out if the differences in release height were simply a matter of differences in height or whether or not it was a result of poor technique, the female shot putters had a better result.

The relative release height (RRH) was calculated by dividing the height of the subject by the measured release height of the centre of gravity of the shot and then multiplied by 100 to give the percentage of release height that was due to standing height. Relative release height was calculated in order to eliminate any advantage the male shot putter had over the females as a result of his greater standing height and make it easier for gender comparison. The male subject's standing height accounted for 83.63% of his release height while the females' average standing height accounted for 82.98% of their average release height of the shot. Therefore, the women maximized their potential release height better than the male subject in the study.

The male shot putter in this study also released the shot 0.8 degrees lower than the average release angle of the females with a measured release angle of 34.4 degrees compared to the females' average release angle of 35.2 degrees. The release angles for all of the subjects in the study fall within the 31-36 degree release angles observed in elite shot putters (M. Young, 2004). In terms of the release velocity, the male athlete released the shot 1.09m/s faster than the females. All else being equal (release height and release angle) the male athlete would still throw the shot further than the two females because of the substantially higher release velocity. According to previous research studying the dynamics of shot putting, within certain limits speed of release is more important to an athlete than the use of an optimum angle (Dyson, 1973; Linthorne, 2001).

Although not as significant as release velocity, horizontal release distance is another variable that can significantly affect throw distance. The distance of the throw is measured from the inside edge of the toe board to where the centre of gravity of the shot lands. Fig. C-2 includes the values for the horizontal release distance of each athlete. Positive numbers indicate that the athlete released the shot in front of the toe board whereas negative numbers indicate that the shot was released from behind the toe board. Thus, the *measured* distance of the throw is the sum of how far the athlete actually threw the shot and the horizontal release distance. Therefore, a shot putter that is capable of throwing the shot 16m but has a negative horizontal release distance of -0.4m, then the measured distance of the throw will only be 15.6m – a significant difference considering many shot put competitions can be won or lost by only a few centimeters.

The females both released the shot behind the toe board which decreased their measured throw distance. In fact, the females released the shot 36cm behind the point where the male shot putter released the shot. Further analysis of this variable discovered that part of the 36cm difference in horizontal release distance of the shot was a result of the female shot putters not utilizing the full diameter of the circle. The distance that the front foot was at release for each of the females was substantially farther behind the inside edge of the toe board than the male shot putter's was. More specifically, the male shot putter's front foot was 0.22cm closer to the toe board than the average distance for the females. Hence, the females can improve their horizontal release distance considerably by moving closer to the front toe board. Everything else being equal, if the females improve their horizontal release distance and just throw even with the toe board (having a horizontal release distance of 0m) then they could improve their throw distance by 2.4%. It must be noted however that although this was a technique error found in the females and not the male subject, this finding may be unique to the subjects in this small group.

Subsequently, the average angular velocity of the shoulder girdle for the second turn and the angular velocity from second single-support to release were adjusted by eliminating the over-rotation of the shoulders. Therefore, the average angular velocity of the second turn was calculated from the orientation of the shoulders from second single-support to where the shoulder rotation should have been at critical instant, and the angular velocity from second double-support to the same position the shoulders should have been in for an effective release. Analyzing these angular velocities yield very different results.

The adjusted average angular velocity of the second turn for the females is 623.88deg/s and to release is now 904.85deg/s (originally 664.81deg/s and 936.95deg/s respectively). For the male subject, the average second turn angular velocity becomes 525.88deg/s from the original 530.16deg/s, and the angular velocity of the shoulder girdle from second double-support to release changes from 767.60deg/s to 1004.82deg/s. Thus, the male subject actually has an angular velocity of 99.97deg/s faster during second double-support than the females. However, the females' average angular velocity of the shoulder girdle through the second turn and to release remains 98deg/s faster than the male subject in this study. This data suggests that the male subject actually had a greater angular acceleration of the shot through the power position (from second single-support to release) than the females did as the females had a greater shoulder girdle angular velocity coming out of the first turn.

Angular velocities of the hips and trunk may not be the critical factor in determining the final measured distance of the throw considering the fact that the females had greater angular velocities of each of these segments (hips and shoulders) yet threw approximately 1.66 meters shorter than their male counter part. This preliminary finding may be supported by the research as two previous studies did not cite hip or shoulder angular velocities to be critical factors in shot put distances (Alexander, 1996; M. Young, Li, L., 2005). When analyzing the angular velocities of four of the finalists at the 1996 Olympic Summer Games in Atlanta, the gold medalist Arsi Harju from Finland had a second turn angular velocity almost 100-deg/s slower than the fifth place finisher in the same event (Taylor, 2004).

Knee angles also varied greatly between the genders throughout the skill. Young and Li (2005) and Alexander et al. (1996) both recognized the importance of the right knee flexion angle at second single support. The right knee is the posterior knee that initiates the upward drive of the shot through the power position. The greater the flexion in the right knee at second single-support, the greater the stretch in the right quadriceps muscles as they eccentrically contract while the athlete's centre of gravity moves over the right leg.

The 34.7 degree difference in the measured angle of the right knee during right foot touchdown is substantial for two reasons: In terms force production, a smaller degree of flexion in the females' right knee means that there is less stretch in the right quadriceps muscles that means a less efficient stretch-reflex and secondly, in terms of range of motion, the range of motion that the shot can potentially travel in the vertical direction is limited.

In the power position, the athlete has both feet in contact with the surface of the circle and the athlete should continue to have the centre of gravity closer to the back leg. During the power position, the athlete wants to forcefully extend both knees and continue to move the shot horizontally and vertically. Again, the greater the knee flexion angle, the more range of motion the athlete has to exert force onto the shot. The male athlete continues to have a greater knee flexion angle than the females (63-degrees for the male compared to an average of 53.45-degrees for the females).

Although males are capable of having much stronger legs than their female counterparts, females are able of generating a significant amount of force with their quadriceps and are competent to support themselves in a position of deep knee flexion. Weightlifting is an example of a sport in which females acquire a deep knee flexion (90 degrees or greater) and are able to explosively extend the knees with a great deal of power and accelerate a significant amount of weight vertically – there is no reason why female shot putters can not perform a similar movement.

In terms of "loading the back leg" for a better force producing phase and maximizing the range of motion of the shot, the maximum knee flexion angle achieved by the athlete during the second single-support phase is almost more important. Many elite shot putters lower their centre of gravity further by allowing their right knee to absorb the vertical forces in the negative direction just after the right foot touches down close to the middle of the circle. As long as the athlete does not significantly lower their centre of gravity, this slight lowering of the centre of gravity can aid in eccentrically loading the right leg. All three of the athletes used in this pilot study increased their right knee flexion angle following the right foot touchdown. The average maximum knee flexion angle for the females was 71.1-degrees and the male's maximum knee flexion angle was 83.7-degrees. In the case of the females however, the increase in knee flexion angle was too large (23.8-degrees) and too much energy was spent in the vertical direction as opposed to concentrating on increasing the horizontal velocity on the shot (see Fig. C-7).

The measurements calculated for each gender during the power position show very different positions reached for males and females. The power position is a critical aspect of the skill and the phase in which the rotational shot put technique is credited with having the athletes in a more desirable position over those using the glide technique

(Hay, 1993). Thus, the differences between the genders during this phase of the skill also warrant further research.

Maximizing the range of motion of the shot has briefly been discussed in terms of knee flexion angles; however a shot putter can also increase the range of motion of the shot by laterally flexing the trunk and flexing the hips and then using the back extensors and trunk external rotators on the left side of the body and the trunk internal rotators on the right side of the body to help propel the shot in a vertical and horizontal direction. The maximum knee angle for all of the athletes occurred during the second single-support phase, whereas the maximum lateral trunk flexion angle occurred for all subjects during the second double-support phase – in other words, when the athletes moved into the power position.

The linear velocity of the shot is another important variable of the skill to consider when analyzing the rotational shot put technique. Overall, the male averaged greater linear velocities of the shot throughout the entire skill however more subjects are required to determine if these are differences due to gender or due to the individual differences (the linear velocities of the females used in this pilot study varied greatly).

There are many other variables that were measured in this pilot study that showed significant differences between the male and female subjects. Although the major contributors to the overall throw distance were discussed in detail, the roles these other variables play in terms of differences in the rotational shot put techniques between males and females are not yet understood. Do the differences in these other variables lead to the differences in the variables recognized to be major contributors to the throw distance? Are the differences in these variables a result of the different anthropometry of males and females? These are questions that beg for further research and must be answered first before real conclusions about the female rotational shot put technique can be made.

Table RD-1: Start position and maximum backswing raw data for pilot study

CALCULATED VARIABLES

Phase of the skill	Variable(s) measured	F-1	F-2	F-average	M-1	Difference
Start position	Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (deg)	2.5	215.6	109.05	189.5	80.45
	Angle formed between the line of the hips and the midline of the circle (deg)	4.2	198.7	101.45	173.4	71.95
	Left knee flexion (deg)	88.6	64.8	76.70	86.8	10.10
	Trunk flexion (deg)	35.6	19.1	27.35	27.2	-0.15
	Left hip flexion (deg)	89.4	60.4	74.90	81.4	6.50
	Height of centre of gravity of the shot (metres)	1.06	1.9	1.48	1.82	0.34
	Left shoulder abduction (deg)	92.5	89.8	91.15	109.3	18.15
	Width of base of support (width)	0.89	0.74	0.82	0.87	0.06
Maximum backswing	Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (deg)	214.9	238	226.45	217.2	-9.25
	Angle formed between the line of the hips and the midline of the circle (deg)	199.7	242.4	221.05	215.7	-5.35
	Shoulder-hip separation (deg)	15.2	4.4	9.80	1.5	-8.30
	Left knee flexion (deg)	97.2	84.8	91.00	71.6	-19.40
	Trunk flexion (deg)	27	27.7	27.35	22.2	-5.15
	Left hip flexion (deg)	79.9	58.8	69.35	42.6	-26.75
	Height of the shot's centre of gravity (m)	1.11	1.68	1.40	1.89	0.50
	Left shoulder flexion (deg)	116.8	92.2	104.50	139.4	34.90

Table RD-2: First turn raw data for pilot study

CALCULATED VARIABLES						
Phase of the skill	**Variable(s) measured**	**F-1**	**F-2**	**F-average**	**M-1**	**Difference**
First turn	Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (FSS) (deg)	137.5	145.4	141.45	105.2	-36.25
	Angle formed between the line of the hips and the line perpendicular to the midline of the circle (FSS) (deg)	123	148.5	135.75	122.1	-13.65
	Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (SSS) (deg)	287.3	294.3	290.80	254	-36.80
	Angle formed between the line of the hips and the line perpendicular to the midline of the circle (SSS) (deg)	261.9	336.2	299.05	275.5	-23.55
	First turn average angular velocity of the hips (deg)	274.72	271.21	272.97	167.7	-105.27
	First turn average angular velocity of the shoulders (deg)	265.31	227.66	246.49	217.83	-28.66
	Shoulder-hip separation (SSS) (deg)	25.4	58.1	41.75	21.5	-20.25
	Horizontal linear velocity of the shot through the first turn (m/s)	1.42	0.82	1.12	1.2	0.08
	Right shoulder abduction (deg)	73.5	98.7	86.10	78.3	-7.80
	Right hip abduction during leg sweep (deg)	29.8	28	28.90	37.7	8.80
	Lateral trunk flexion during leg sweep (to the right) (deg)	18	0	9.00	2.9	-6.10
	Length of "step" into the centre of the circle (m)	1.18	0.9	1.04	1.1	0.06
	Height of shot's centre of gravity at single support (m)	1.21	1.3	1.26	1.47	0.22
	Height of shot's centre of gravity at take-off (m)	1.28	1.35	1.32	1.47	0.16
	Height of shot's centre of gravity at peak height of airborne phase (m)	1.28	1.36	1.32	1.47	0.15
	Right hip extension at single-support (deg)	-43.7	-26.5	-35.10	2.3	37.40
	Extension of left knee at take-off (deg)	-26.8	-20	-23.40	27.2	50.60
	Right hip abduction during leg sweep (deg)	31	28	29.50	37.7	8.20
	Lateral trunk flexion at leg sweep (deg)	0	0	0.00	0	0.00
	Left knee flexion at single support (deg)	79.8	45.2	62.50	83.3	20.80
	Angle formed between the line from the left toe and left hip with the vertical (lean into the circle) during the right leg sweep (deg)	23.4	10.3	16.85	14	-2.85

Table RD-3: Second turn raw data for pilot study

CALCULATED VARIABLES						
Phase of the skill	**Variable(s) measured**	**F-1**	**F-2**	**F-average**	**M-1**	**Difference**
Second turn	Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (SDS) (deg)	167.8	147.3	157.55	166.8	9.25
	Angle formed between the line of the hips and the line perpendicular to the midline of the circle (SDS) (deg)	97.5	130.8	114.15	74.5	-39.65
	Second turn angular velocity of the hips (deg/s)	586.3	471.46	528.88	491.36	-37.52
	Second turn angular velocity of the shoulders (deg/s)	707.06	622.55	664.81	530.16	-134.65
	Second turn linear velocity of the shot (SSS-SDS) (m/s)	0.92	0.82	0.84	0.97	0.13
	Linear velocity of the shot through the power position (m/s)	5.28	5.9	5.59	5.76	0.17
	Average linear velocity of the shot from SSS-REL (m/s)	2.5	2.57	2.54	3	0.47
	Shoulder-hip separation (SDS) (deg)	70.3	16.5	43.40	92.3	
	Right shoulder flexion at max. right knee during single-support (deg)	141.1	74.8	107.95	70.1	-37.85
	Trunk flexion at maximum right knee flexion during 2nd single-support (deg)	28.5	30.6	29.55	30.3	0.75
	Maximal right hip flexion during second turn (deg)	66.5	62.7	64.60	69.9	5.30
	Lateral trunk flexion at power position (deg)	13.8	9.6	11.70	21.8	10.10
	Width of base of support at 2nd double support (m)	0.55	0.62	0.59	0.74	0.16
	Height of shot's centre of gravity at 2nd single support (m)	1.27	130	65.64	1.47	-64.17
	Height of shot's centre of gravity at the beginning of double support (m)	1.22	1.22	1.22	1.42	0.20
	Right knee flexion at right foot touch down (deg)	53	41.7	47.35	82	34.65
	Maximum right knee flexion during second turn (deg)	77.6	64.6	71.10	83.7	12.60
	Trunk flexion at right foot touchdown (deg)	41.7	38.5	40.10	23.8	-16.30
	Left shoulder flexion at right foot touch down (deg)	117.9	81.5	99.70	98.2	-1.50
	Right knee angle at power position (deg)	57.3	49.6	53.45	63	9.55
	Angular velocity of the right horizontal shoulder adduction (deg/s)	109.01	323.28	216.15	256.39	40.25

Table RD-4: Release phase raw data and relative release height calculated for pilot study

CALCULATED VARIABLES						
Phase of the skill	**Variable(s) measured**	**F-1**	**F-2**	**F-average**	**M-1**	**Difference**
Release	Horizontal release distance(m)	-0.61	-0.03	-0.32	0.04	0.36
	Angle formed between the line of the hips and the line perpendicular to the midline of the circle (deg)	-11.9	0	-5.95	-24.6	-18.65
	Angle formed between the line of the shoulders and the line perpendicular to the midline of the circle (deg)	-42.9	-17.6	-30.25	-25.1	5.15
	Shoulder-hip separation (REL) (deg)	-31	-17.6	-24.30	-0.5	23.80
	Distance of left toe from toe board (m)	-0.31	-0.36	-0.34	-0.12	0.22
	Angular velocity of the right elbow at release (deg/s)	1262.93	1347.41	1305.17	1190.23	-114.94
	Angular velocity of the right wrist at release (deg/s)	138.2	106.51	122.36	525.56	403.21
	Right knee angular velocity during force production (deg/s)	247.64	117.6	182.62	140.33	-42.29
	Release height (m)	1.92	1.9	1.91	2.2	0.29
	Release angle (deg)	34.8	35.6	35.20	34.4	-0.80
	Release velocity (m/s)	8.1	9.17	8.64	9.72	1.09
	Throw Distance (m)	13.74	13.40	13.40	15.05	1.66
Others	Standing height (m)	1.55	1.62	1.59	1.84	0.26
	Release height (m)	1.92	1.9	1.91	2.2	0.29
	Relative release height	80.73	85.26	82.98	83.64	87.93

Table RD-5: First turn angular velocity data for each subject

	FIRST TURN													
	Double Support							Single Support Left Leg						
	MBS	FSS	Time (sec)	MBS	FSS	Ang. Dis.	Ang. Vel.	FSS	LFTO	Time (sec)	FSS	LFTO	Ang. Dis.	Ang. Vel.
F-1	1.835	2.419	0.584	214.9	137.5	-77.4	-132.534	2.419	2.886	0.467	137.5	301.6	164.1	351.3919
F-2	1.685	2.335	0.65	238	145.4	-92.6	-142.462	2.335	2.936	0.601	145.4	273.8	128.4	213.6439
M-1	1.534	2.402	0.868	217.2	105.2	-112	-129.032	2.402	2.919	0.517	105.2	254	148.8	287.8143
F-average			0.739333			-103.433	-139.192			0.511667			169.6667	342.8777

	FIRST TURN													
	Airborne													
F-1	2.886	2.919	0.033	301.6	287.3	-14.3	-433.333	1.835	2.919	1.084	214.9	287.3	287.6	265.3137
F-2	2.936	3.019	0.083	273.8	294.3	20.5	246.988	1.685	3.019	1.334	238	294.3	303.7	227.6612
Georgette	2.902	2.936	0.034	325.3	295.8	-29.5	-867.647	1.451	2.936	1.485	249.1	295.8	313.3	210.9764
M-1	2.919	2.919	0	254	254	0	0	1.534	2.919	1.385	217.2	275.5	301.7	217.8339
Averages			0.0375			-5.825	-263.498			1.322				230.4463
F-average			0.05			-7.76667	-351.331			1.301				234.6504

Key			
MBS	Maximum backswing	F-1	Female subject #1
FSS	First single-support	F-2	Female subject #2
LFTO	Left foot take-off	M-1	Male subject #1
SSS	Second single-support	F-average	Female average
Ang. Dis.	Angular displacement		
Ang. Vel.	Angular velocity		

Table RD-6: Second turn angular velocity data for each subject

	SECOND TURN													
	Single Support Right Leg							To Release						
	SSS	SDS	Time (sec)	SSS	SDS	Ang. Dis.	Ang. Vel.	SDS	Release	Time (sec)	SDS	Release	Ang. Dis.	Ang. Vel.
F-1	2.919	3.186	0.267	287.3	167.8	-119.5	-447.566	3.186	3.386	0.2	167.8	-42.9	210.7	1053.5
F-2	3.019	3.319	0.3	294.3	147.3	-147	-490	3.319	3.52	0.201	147.3	-17.6	164.9	820.398
M-1	2.919	3.236	0.317	254	166.8	-87.2	-275.079	3.236	3.486	0.25	166.8	-25.1	191.9	767.6
Average females			0.272333			-127.433	-466.922			0.217			187.6667	874.4993

	SECOND TURN														
	Second Turn							Modified Second Turn				Modified to Release			
	SSS	Release	Time (sec)	SSS	Release	Ang. Dis.	Ang. Vel.	SSS	PTM	Time (sec)	Ang. Vel.	SDS	PTM	Time (sec)	Ang. Vel.
F-1	2.919	3.386	0.467	287.3	42.9	330.2	707.0664	287.3	0	0.45	638.4444	167.8	0	0.167	100
F-2	3.019	3.52	0.501	294.3	17.6	311.9	622.5549	294.3	0	0.483	609.3168	147.3	0	0.183	804
Georgette	2.936	3.436	0.5	295.8	7.4	303.2	606.4	295.8	0	0.484	611.157	180	0	0.234	769.
M-1	2.919	3.486	0.567	275.5	25.1	300.6	530.1587	254	0	0.483	525.8799	166.8	0	0.166	1004
Average females			3.447333			22.63333	315.1				0.472333				0.19

Key			
MBS	Maximum backswing	F-1	Female subject #1
FSS	First single-support	F-2	Female subject #2
LFTO	Left foot take-off	M-1	Male subject #1
SSS	Second single-support	F-average	Female average
Ang. Dis.	Angular displacement		

HIPS							
Modified Second turn				Modified to Release			
SSS	PTM	Time (sec)	Ang. Vel.	SDS	PTM	Time (sec)	Ang.
261.9	0	0.45	582	97.5	0	0.167	583.
236.2	0	0.483	489.0269	130.8	0	0.183	714.
256.6	0	0.484	530.1653	129.5	0	0.234	553.
275.5	0	0.483	570.3934	74.5	0	0.166	448.
			0.472333				0.19

APPENDIX D

SUBJECT CHARACTERISTICS

SUBJECT CHARACTERISTICS

SUBJECT	VARIABLES	
FEMALES	**Height (cm)**	**Weight (kg)**
F1	167.64	100.00
F2	172.72	90.91
F3	171.45	87.73
F4	175.00	84.09
F5	175.00	79.55
F6	172.72	88.64
F7	176.00	105.00
F8	176.53	100.00
Mean	173.38	91.99
MALES		
M1	190.50	131.82
M2	193.04	129.55
M3	203.20	143.18
M4	0.00	147.73
M5	190.50	111.36
M6	185.42	159.09
M7	185.42	120.45
M8	186.69	136.36
M9	182.88	127.27
M10	185.42	109.09
Mean	170.31	131.59

APPENDIX E

FEMALE SUBJECT RAW DATA

FEMALE DATA (Maximum Backswing Variables)

SUBJECT	Width of first base of support (cm)	Left knee flexion (deg)	Trunk flexion (deg)	Left hip flexion (deg)	Relative height of the shot's centre of gravity (cm)	Left shoulder flexion (deg)
	VARIABLES					
F1	65.62	62.60	19.30	41.70	1.30	62.30
F2	65.33	68.20	25.30	33.30	1.36	78.90
F3	71.62	59.00	30.00	32.20	1.24	90.00
F4	68.24	100.30	27.20	67.80	1.41	108.50
F5	66.87	88.00	6.90	17.60	1.45	82.80
F6	75.87	96.30	35.10	90.10	1.36	112.10
F7	83.69	72.70	30.70	56.20	1.40	100.10
F8	87.70	17.00	29.30	8.30	1.31	132.70
Mean	**73.12**	**70.51**	**25.48**	**43.40**	**0.74**	**95.93**
Std. Dev.	**8.57**	**26.53**	**8.79**	**26.91**	**0.04**	**22.10**

FEMALE DATA (First Turn Variables)

SUBJECTS	Average horizontal linear velocity of the shot through the first turn (m/s)	Right shoulder abduction @ FSS (deg)	Length of "step" across the circle (m)	Relative height of shot's centre of gravity at single support @ FSS	Relative height of shot's centre of gravity @ take-off	Relative height of shot's centre of gravity at peak height of airborne phase (PA)	Right hip flexion at single-support @ leg sweep (deg)	Flexion of left knee @ take-off (deg)	Right hip abduction during leg sweep (deg)	Angle of trunk to the right of vertical @ leg sweep (deg)	Left knee flexion @ FSS (deg)
F1	0.78	82.70	0.61	0.8	0.80	0.80	-14.90	16.40	13.90	-16.20	37.80
F2	0.85	51.40	0.71	0.76	0.72	0.73	4.10	22.00	32.80	-15.20	66.10
F3	0.79	70.40	0.56	0.76	0.85	0.86	33.00	37.20	49.90	10.10	58.50
F4	0.11	86.40	0.6	0.76	0.82	0.81	30.30	29.20	29.20	5.10	26.80
F5	0.80	73.10	0.61	0.70	0.75	0.74	0.00	17.80	17.80	-13.40	77.20
F6	0.84	81.50	0.75	*0.82*	0.83	0.83	20.60	22.10	39.70	7.90	77.80
F7	0.92	94.90	0.48	0.8	0.80	0.79	14.00	3.70	31.40	3.40	66.60
F8	0.34	86.40	0.62	0.82	0.83	0.83	14.80	11.90	34.00	1.60	50.10
Mean	**0.68**	**78.35**	**0.62**	**0.78**	**0.80**	**0.80**	**12.74**	**20.04**	**31.09**	**-2.09**	**57.61**
Std. Dev.	**0.29**	**13.36**	**0.08**	**0.04**	**0.04**	**0.04**	**15.98**	**10.27**	**11.43**	**10.97**	**18.30**

FEMALE DATA (Second turn Variables: Second Single-Support)

	VARIABLES							
SUBJECTS	**Relative height of shot's centre of gravity @ SSS**	**Trunk flexion @ SSS (deg)**	**Left shoulder flexion @ SSS (deg)**	**Right knee flexion @ SSS (deg)**	**Right shoulder abduction @ max. right knee during SSS (deg)**	**Trunk flexion @ maximum right knee flexion during SSS (deg)**	**Maximal right hip flexion during second turn (deg)**	**Maximum right knee flexion during second turn (deg)**
F1	0.79	34.50	96.80	37.80	83.10	39.60	72.70	65.80
F2	0.72	25.40	78.90	47.60	56.90	35.70	59.30	64.30
F3	0.86	20.10	82.40	43.00	67.10	23.40	44.20	47.80
F4	0.80	30.10	92.00	55.40	105.90	39.80	78.20	64.70
F5	0.73	26.40	88.30	50.60	88.80	31.30	63.30	60.40
F6	0.83	42.30	118.30	48.10	88.60	30.60	69.30	74.30
F7	0.79	39.60	85.40	45.40	73.40	25.90	62.10	55.10
F8	0.82	26.30	60.80	51.90	75.00	47.20	78.50	57.90
Mean	**0.71**	**30.59**	**87.86**	**47.48**	**79.85**	**34.19**	**65.95**	**61.29**
Std. Dev.	**0.05**	**7.62**	**16.35**	**5.48**	**15.12**	**7.92**	**11.36**	**7.95**

FEMALE DATA (Second turn Variables: Second Double-Support)

	VARIABLES							
SUBJECTS	Relative height of shot's CofG @ the beginning SDS	Right knee angle @ power position (deg)	Right knee angular velocity during force production (deg/s)	Width of base of support @ SDS (m)	Lateral trunk flexion @ power position (deg)	Second turn average linear velocity of the shot (SSS-SDS)(m/s)	Average linear velocity of the shot through the power position (m/s)	Average linear velocity of the shot from SSS-REL (m/s)
F1	0.66	57.10	307.76	0.33	23.10	1.12	6.07	2.69
F2	0.65	48.70	332.76	0.32	29.20	1.13	5.41	3.01
F3	0.75	56.90	393.10	0.24	17.70	1.12	6.38	3.44
F4	0.71	68.50	285.34	0.3	21.40	0.94	5.57	2.85
F5	0.66	40.80	344.83	0.39	23.50	0.84	6.46	3.38
F6	0.78	69.40	427.59	0.36	17.70	0.86	5.93	2.76
F7	0.73	55.10	188.00	0.43	16.50	0.92	5.67	2.64
F8	0.72	57.90	259.30	0.37	27.00	1.90	8.79	5.30
Mean	**0.71**	**56.80**	**317.34**	**0.34**	**22.01**	**1.10**	**6.29**	**3.26**
Std. Dev.	**0.05**	**9.42**	**75.69**	**0.06**	**4.60**	**0.34**	**1.08**	**0.88**

FEMALE DATA (Release variables and distance thrown)

	VARIABLES						
SUBJECTS	**Horizontal release distance (cm)**	**Distance of left toe from toe board (cm)**	**Release height (cm)**	**Release angle (deg)**	**Release velocity (m/s)**	**Relative release height**	**Throw Distance (m)**
F1	13.69	12.01	187.52	36.10	10.19	1.10	14.20
F2	9.97	9.34	190.03	34.90	10.24	1.09	13.35
F3	-5.71	50.07	195.10	27.00	9.46	1.13	13.76
F4	-12.34	23.36	181.33	29.80	11.13	1.08	14.55
F5	23.03	6.07	189.09	33.00	11.48	1.08	15.12
F6	-4.36	18.42	203.52	33.70	8.79	1.32	13.62
F7	-21.73	25.95	191.02	28.60	8.31	1.18	13.03
F8	1.91	10.74	209.42	32.10	11.70	1.19	13.60
Mean	**0.56**	**19.50**	**193.38**	**31.90**	**10.16**	**1.15**	**13.90**
Std. Dev.	**14.61**	**14.19**	**9.09**	**3.17**	**1.25**	**0.08**	**0.68**

APPENDIX F

MALE SUBJECT RAW DATA

MALE DATA (Maximum Backswing Variables)

	VARIABLES					
SUBJECT	Width of first base of support (cm)	Left knee flexion (deg)	Trunk flexion (deg)	Left hip flexion (deg)	Relative height of the shot's centre of gravity (cm)	Left shoulder flexion (deg)
F1	82.97	51.70	25.30	51.50	0.73	112.50
F2	87.69	31.80	12.40	10.20	0.79	89.40
F3	76.97	66.40	24.70	42.30	0.73	86.60
F4	61.34	24.20	45.20	29.50	0.74	92.10
F5	56.51	65.30	24.90	38.50	0.64	86.20
F6	82.64	34.60	57.90	46.40	0.64	120.40
F7	58.70	89.00	27.80	61.50	0.71	115.50
F8	76.72	62.70	37.90	73.80	0.73	89.70
Mean	**70.62**	**57.11**	**31.92**	**47.50**	**0.71**	**99.57**
Std. Dev.	**12.63**	**21.64**	**13.19**	**18.60**	**0.19**	**13.65**

MALE DATA (First Turn Variables)

SUBJECTS	VARIABLES: Average horizontal linear velocity of the shot through the first turn (m/s)	Right shoulder abduction @ FSS (deg)	Length of "step" across the circle (m)	Relative height of shot's centre of gravity at single support @ FSS	Relative height of shot's centre of gravity @ take-off	Relative height of shot's centre of gravity at peak height of airborne phase (PA)	Right hip flexion at single-support @ leg sweep (deg)	Flexion of left knee @ take-off (deg)	Right hip abduction during leg sweep (deg)	Angle of trunk to the right of vertical @ leg sweep (deg)	Left knee flexion @ FSS (deg)
F1	0.59	69.20	0.57	0.71	0.78	0.76	45.50	27.20	25.30	7.60	63.50
F2	0.73	82.50	0.65	0.79	0.77	0.75	11.10	20.30	31.40	-11.90	59.80
F3	0.52	84.40	0.69	0.77	0.76	0.77	-12.50	2.70	11.20	-25.90	72.80
F4	0.65	75.80	0.68	0.68	0.82	0.81	39.90	37.10	51.10	5.00	70.60
F5	0.39	68.70	0.52	0.75	0.79	0.78	0.00	26.60	33.00	-15.80	72.10
F6	0.47	77.30	0.61	0.66	0.80	0.78	31.40	33.30	44.70	4.20	47.70
F7	0.63	72.10	0.54	0.77	0.83	0.84	0.00	25.70	20.10	-16.50	79.40
F8	0.77	96.30	0.56	0.71	0.86	0.85	36.40	37.40	29.30	-14.20	64.00
Mean	**0.60**	**79.42**	**0.6**	**0.74**	**0.80**	**0.79**	**19.98**	**26.28**	**29.17**	**-8.86**	**64.37**
Std. Dev.	**0.13**	**10.58**	**0.06**	**0.05**	**0.03**	**0.03**	**19.56**	**9.99**	**11.87**	**10.92**	**10.51**

MALE DATA (Second turn Variables: Second Single-Support)

SUBJECTS	Relative height of shot's centre of gravity @ SSS	Trunk flexion @ SSS (deg)	Left shoulder flexion @ SSS (deg)	Right knee flexion @ SSS (deg)	Right shoulder abduction @ max. right knee during SSS (deg)	Trunk flexion @ maximum right knee flexion during SSS (deg)	Maximal right hip flexion during second turn (deg)	Maximum right knee flexion during second turn (deg)
F1	0.76	22.60	63.60	29.40	62.20	31.60	47.10	69.40
F2	0.77	34.20	92.10	53.90	99.10	40.90	66.60	68.90
F3	0.79	44.50	91.40	44.80	90.30	38.80	61.10	72.00
F4	0.79	22.50	78.30	39.20	47.30	33.20	38.20	69.10
F5	0.75	32.60	91.30	42.90	82.80	31.00	58.20	65.20
F6	0.76	27.20	59.70	23.10	84.80	30.40	42.20	52.00
F7	0.81	31.00	41.40	54.00	88.40	25.90	57.30	68.90
F8	0.82	23.50	67.80	31.50	67.80	37.40	59.10	64.10
Mean	**0.77**	**31.06**	**76.66**	**36.72**	**78.83**	**34.21**	**56.64**	**22.57**
Std. Dev.	**0.03**	**7.46**	**17.87**	**13.34**	**15.32**	**4.60**	**11.13**	**7.85**

MALE DATA (Second turn Variables: Second Double-Support)

SUBJECTS	VARIABLES							
	Relative height of shot's CofG @ the beginning SDS	Right knee angle @ power position (deg)	Right knee angular velocity during force production (deg/s)	Width of base of support @ SDS (m)	Lateral trunk flexion @ power position (deg)	Second turn average linear velocity of the shot (SSS-SDS)(m/s)	Average linear velocity of the shot through the power position (m/s)	Average linear velocity of the shot from SSS-REL (m/s)
F1	0.64	51.40	0.76	0.36	18.90	1.28	6.40	3.33
F2	0.66	62.30	0.77	0.29	31.40	0.86	5.20	2.76
F3	0.67	67.20	0.79	0.33	35.20	1.22	5.14	2.80
F4	0.68	41.00	0.79	0.24	27.30	1.05	5.56	3.08
F5	0.67	54.00	0.75	0.34	23.70	1.01	5.43	3.39
F6	0.67	43.60	0.76	0.23	9.70	0.83	6.65	3.24
F7	0.74	57.50	0.81	0.46	17.60	2.02	5.47	3.86
F8	0.69	59.50	0.82	0.34	21.40	1.39	5.63	3.18
Mean	**0.68**	**56.38**	**0.77**	**0.33**	**22.57**	**1.19**	**5.71**	**3.14**
Std. Dev.	**0.03**	**8.98**	**0.03**	**0.07**	**7.85**	**0.35**	**0.56**	**0.34**

MALE DATA (Release variables and distance thrown)

SUBJECTS	Horizontal release distance (cm)	Distance of left toe from toe board (cm)	Release height (cm)	Release angle (deg)	Release velocity (m/s)	Relative release height	Throw Distance (m)
	VARIABLES						
F1	10.13	15.20	206.96	38.90	11.35	10.13	15.20
F2	17.94	10.49	212.89	29.00	9.22	17.94	10.49
F3	20.75	2.97	221.48	40.40	11.56	20.75	2.97
F4	2.79	19.44	209.29	40.10	11.20	2.79	19.44
F5	9.62	37.98	205.59	31.90	9.11	9.62	37.98
F6	1.49	29.28	213.76	35.80	11.83	1.49	29.28
F7	15.19	18.84	219.40	34.50	10.62	15.19	18.84
F8	22.61	14.58	228.24	36.00	12.60	22.61	14.58
Mean	**15.27**	**16.96**	**213.84**	**35.70**	**10.65**	**15.27**	**16.96**
Std. Dev.	**9.56**	**10.35**	**8.51**	**3.56**	**1.24**	**9.56**	**10.35**

APPENDIX G

OVERHEAD CAMERA RAW DATA

OVERHEAD CAMERA VARIABLES

	M1	M2	F1	F2	F3	F-average	F. SD	M-average	M. SD
Angular velocity of the shoulders from SSS-RELh	602.31	680.37	577.78	646.89	635.01	52.316923	637.06	49.14	0.48
Angular velocity of the shoulders from SSS-REL	568.86	684.06	595.20	627.84	635.70	44.947559	634.86	93.34	0.50
Angular velocity of the hips from SSS-RELh	546.88	623.56	477.33	537.11	546.00	73.515804	586.37	55.84	0.27
Angular velocity of the hips from SSS-REL	544.09	583.23	430.00	520.99	511.40	77.062814	549.35	7.43	0.24
Shoulder-hip separation at SSS	24.00	25.70	45.80	48.50	40.00	12.457528	24.35	0.49	0.08
Angular velocity of the shoulders from SDS-RELh	1051.33	1016.00	896.99	839.50	917.50	90.019426	974.00	109.37	0.30
Angular velocity of the shoulders from SDS-REL	798.40	932.00	861.11	787.04	860.05	72.487313	824.31	36.64	0.26
Angular velocity of the hips from SDS-RELh	432.67	695.33	623.49	617.00	645.28	43.472551	520.00	123.51	0.19
Angular velocity of the hips from SDS-REL	798.80	587.00	488.89	578.70	551.53	54.407903	636.31	229.80	0.35
Shoulder-hip separation at SDS	88.20	45.90	39.30	42.30	42.50	3.3045423	66.30	30.97	0.24

APPENDIX H

RELIABILITY TEST RAW DATA

RELIABILITY TEST

	Trunk flexion at maximum backswing (deg)	Right hip abduction at leg sweep (deg)	Length of first step (m)	Height of shot's centre of gravity at SSS (m)	Maximum knee flexion during second turn (deg)	Lateral trunk flexion in power position (deg)	Release velocity (m/s)	Release angle (deg)	Release height (m)	Horizontal release distance (m)
Mean	26.6	31.2	1.16	1.3	74.5	14.4	7.92	35.1	1.92	0.062
Std. Dev.	0.8	1.2	0.01	0.01	0.9	0.2	0.14	0.6	0.01	0.002
Std. Error	0.2	0.3	2.43E-03	2.14E-03	0.2	0.1	0.04	0.2	1.82E-03	0.001
Variance	0.6	1.5	8.86E-05	6.86E-05	0.8	0.1	0.02	0.4	4.95E-05	3.84E-06
Coeff. of Variation	3.00E-02	3.90E-02	0.01	0.01	1.20E-02	1.70E-02	0.02	1.70E-02	3.66E-03	0.032
Minimum	25.8	29.4	1.14	1.29	73.4	14	7.67	33.9	1.91	0.058
Maximum	28.5	33.2	1.17	1.31	76.9	14.7	8.1	36	1.93	0.064
Range	2.7	3.8	0.03	0.02	3.5	0.7	0.43	2.1	0.02	0.006
Sum	399.7	467.7	17.37	19.44	1118	216.2	118.81	526.3	28.84	0.923
Sum of Squares	10659.5	14603.7	20.12	25.2	83339.5	3117	941.32	18471.1	55.45	0.057
Trials										
14-May	25.80	29.90	1.14	1.31	73.40	14.30	7.93	34.00	1.91	0.058
21-May	27.90	32.30	1.15	1.31	74.10	14.60	7.71	36.00	1.92	0.061
28-May	28.50	30.20	1.16	1.29	75.20	14.60	7.93	33.90	1.92	0.064
4-Jun	26.70	29.70	1.15	1.31	75.00	14.40	7.67	35.10	1.92	0.064
11-Jun	25.80	31.50	1.15	1.29	74.10	14.00	7.93	35.60	1.92	0.064
18-Jun	27.00	32.10	1.17	1.30	73.60	14.70	7.82	35.90	1.92	0.064
25-Jun	26.50	29.40	1.17	1.29	74.20	14.60	7.93	34.80	1.93	0.064
3-Jul	26.90	32.20	1.17	1.29	74.10	14.10	7.82	35.50	1.93	0.061
10-Jul	26.70	32.00	1.16	1.29	74.50	14.70	8.10	35.10	1.92	0.061
17-Jul	25.80	30.60	1.16	1.29	75.20	14.30	8.10	35.20	1.92	0.058
24-Jul	26.90	29.90	1.15	1.29	75.50	14.10	7.93	35.00	1.93	0.061
3-Aug	26.90	30.40	1.15	1.30	76.90	14.50	7.82	35.40	1.93	0.061
10-Aug	25.90	32.60	1.16	1.29	74.00	14.10	8.09	34.60	1.93	0.061
17-Aug	26.60	33.20	1.17	1.29	74.30	14.70	7.93	35.20	1.93	0.061
24-Aug	25.80	31.70	1.16	1.30	73.90	14.50	8.10	35.00	1.91	0.063