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Technique and Performance Level Comparisons of Male and Female Hammer Throwers

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TECHNIQUE AND PERFORMANCE LEVEL COMPARISONS OF MALE AND FEMALE HAMMER THROWERS

by

Suzanne M. Konz

A dissertation submitted to the faculty of

Brigham Young University

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Doctor of Philosophy

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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

Suzanne M. Konz

This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate’s graduate committee, I have read the dissertation of Suzanne M. Konz in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

TECHNIQUE AND PERFORMANCE LEVEL COMPARISONS OF MALE AND FEMALEHAMMER THROWERS

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Department of Exercise Sciences

Doctor of Philosophy

The aim of this study was two-fold: 1) if there were hammer throwing technique differences between genders and 2) what technique parameters helped to determine throw distance. The performances of the top 16 male and female throwers at the 2003 WAC Finals and the top 13 male and female throwers from the 2003 USATF Nationals were examined. Video was captured using three Canon 60 Hz cameras. The best throws of each athlete were digitized and analyzed using the Peak Motus 8.2 motion analysis system. *T tests* revealed that athlete mass, athlete height, velocity at release, timing components, and centripetal force were different between genders. The separation between the shoulders and hips and between the shoulders and the hammer at particular positions during the throw, radius changes at certain phases of the throw, and generation of large centripetal forces helped determine throwing distance. Training would be aided by working on the build-up of centripetal force, the magnitude of radius changes, the separation that occurs between the shoulders and hips, and the separation between the shoulders and hammer.

Keywords: gender differences, technique differences, biomechanical analysis, hammer

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Thank you to my family and friends for their support. You guys have been absolutely amazing through all this. Thank you, God. You never give us more than we can handle but you definitely push us to our limits.

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Technique and Performance Level Comparisons of Male and Female Hammer Throwers

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ABSTRACT

The aim of this study was two-fold: 1) what the hammer throwing technique differences between sexes are and 2) what technique parameters help determine throw distance. The performances of the top 16 male and female throwers at the 2003 World Athletic Final and the top 13 male and female throwers from the 2003 USA Track and Field Nationals were examined. Video was captured using three Canon 60 Hz cameras. The best throws of each athlete were digitized and analyzed using the Peak Motus 8.2 motion analysis system. *T-tests* revealed that athlete mass, athlete height, velocity at release, timing components, and centripetal force were different between sexes. The separation between the shoulders and hips and between the shoulders and the hammer at particular positions during the throw, radius changes at certain phases of the throw, and generation of large centripetal forces helped determine throwing distance. Performance would be aided by working on the development of centripetal force, the magnitude of radius changes, the separation that occurs between the shoulders and hips, and the separation between the shoulders and hammer.

Keywords: sex differences, technique differences, biomechanical analysis

INTRODUCTION

The hammer throw is a complex event combining linear and angular motion. Three main factors determining the distance of a throw are velocity at release, angle of release, and height of release (Dapena, 1984;Hay, 1993). These factors are the culmination of the technique used by the athlete. The basic throwing technique is similar across all throwers but variations are present due to anthropometric, training, and error influences.

Winds initiate the throwing action, (Black, 1989;Bondarchuk, 1982;Woicik, 1980) building up the centrifugal force (Woicik, 1980) and establish the orbit of the ball (Black, 1980;Simonyi, 1980). The winds also help to establish and set the rhythm, radius, high points and low points of the throw (Black, 1980;Bondarchuk, 1982;Simonyi, 1980).

Throwers utilize different methods of getting the hammer moving. Stationary, dynamic, and pendulum starts are the three commonly used. A moving start allows the athlete to utilize momentum to get the hammer moving effectively. The thrower will perform two or three winds. Winds are relaxed and smooth with a long radius. Wind speed is slow and controlled (Simonyi, 1980). The plane of the hammer head’s path during the winds should be relatively flat (Black, 1980;Simonyi, 1980). A thrower is able to control the throw better in its entirety with the flatter wind angle (Simonyi, 1980) due to forces being within the ability of the athlete's strength to control.

A typical starting position with the hips facing the back of the ring and the feet at shoulder width apart, left foot at the rim and the right slightly behind. The thrower's shoulders and trunk are turned far to the right as the ball is swung to the right side. The athlete loads the right side of the body with the movement of the ball to the right side. The left heel comes off the ground to allow greater rotation of the trunk to the right side. The athlete begins the ball moving toward the back of the ring in a curvilinear motion (Bondarchuk, 1982). As the ball moves down the right side, the hips and the feet of the athlete remain facing the back of the ring. The arms of the athlete are extended and relaxed to make the radius of the hammer path as long as possible (Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). The athlete sweeps the ball past the low point which occurs at the back of the ring (Payne, 1980). The hips and the shoulders are parallel as the ball moves through the back of the ring (Bondarchuk, 1982). When the ball passes to the front of the athlete, the athlete lowers the left shoulder to allow the hammer to continue in the circular motion to the left of the athlete.

The athlete shifts body weight slightly to the left to load the left side (Woicik, 1980) as the ball passes up the left side and behind the athlete's head.

The elbows bend and the hands clear the top of the head as the right wrist rolls over the left to help the wind progress behind the head. Once the ball is behind the thrower's head, the thrower turns the head, shoulders, and trunk to the right as the ball reaches the high point of its path. The arms are bent at the elbows as the ball begins to move down the right side as the hands and the hammer clear the head. The thrower extends the arms as quickly as possible to establish a lengthened radius, to push the ball toward low point, and to increase ball speed (Simonyi, 1980). The arms and shoulders are relaxed to help develop the maximal radius of the hammer path again (Black, 1980;Simonyi, 1980). The hips and feet remain facing in the original position. The right foot flattens to help prevent sway and build torque at the hips (Black, 1980;Simonyi, 1980;Woicik, 1980). The second wind follows a similar motion (Simonyi, 1980) but the plane the ball travels is flatter and the velocity of the ball is faster than the first wind (Simonyi, 1980;Woicik, 1980).

The transition into the turns begins at the high point of the final wind. Arms are extended from the bent elbow position as the ball moves down the right side toward low point. The thrower uses the legs and the right arm to drive the ball from the high point to the low point (Black, 1980;Simonyi, 1980). As the ball moves toward the low point in the throw, the athlete drops from an erect position to a squat position, (Woicik, 1980) with the right side loaded. Vertical and horizontal acceleration occurs when the athlete drops into the squat position (Simonyi, 1980).

The athlete shifts the hips and weight to the right as they push the ball to the left (Black, 1980;Simonyi, 1980). As the ball passes low point, weight is shifted to the center as the ball moves toward the left side of the thrower. The athlete pivots to the left on the heel of the left foot and pushes on the toes of the right foot (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). The left foot is now the center of rotation as the turns have begun.

The purpose of the turns is to create the best conditions to increase speed in body and hammer rotation (Bondarchuk, 1982;Simonyi, 1980) with the overall velocity of the hammer being increased to maximum levels at delivery (Black, 1980;Bondarchuk, 1980). Turns in the hammer throw are a series of complete revolutions of the hammer-thrower system following the winds and is characterized by alternating between double support and single support stance (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). Acceleration of the ball must occur smoothly throughout the turns (Bondarchuk, 1980;Dapena, 1984;Simonyi, 1980). The ability to increase velocity during double support is the key to success in the turns (Bondarchuk, 1982). The thrower needs maintain ground contact with the right foot as long as possible in order to impart force to the ball (Bondarchuk, 1980;Bondarchuk, 1982).

The athlete shifts to the right as the ball rises to the left and up the left side of the thrower (Black, 1980) and increases the angle of the orbit. The hips and the shoulders open to a 45° angle as the athlete moves toward single support (Woicik, 1980). The right foot leaves its contact with the ground during each turn as the left great toe reaches approximately 170˚ – 180˚ (Otto, 1988;Simonyi, 1980). The right foot is held off the ground just above the height of the ankle, optimally at 0.3 m away from the left shin (Otto, 1988) and the right knee is close to the inner left thigh (Otto, 1988;Simonyi, 1980). The right foot is kept close to the center of rotation during single support to minimize the loss of inertia potentially slowing the athlete's rotation in the turns (Bondarchuk, 1982;Simonyi, 1980) and having a greater than the effect gravity and friction (Dapena, 1984). Proper right leg activity and foot positioning allows the athlete to actively return to double support as quickly as possible, minimizes ball speed loss, and creates conditions for the greatest velocity increase (Bondarchuk, 1982;Dapena, 1984;Simonyi, 1980).

As the athlete approaches approximately 180°, the athlete shifts from the heel pivot to a roll on the outside of the left foot until the toes are in contact with the ground. When the toes of the left foot come in contact with the ground, the right foot is planted.

The beginning of the double support position allows the athlete to increase torque on the system and add speed to the rotation of the hammer path (Bondarchuk, 1982;Otto, 1988;Simonyi, 1980). Athletes want to extend double support as long as possible in order to generate maximum torque over the maximum time possible (Black, 1980;Bondarchuk, 1982;Dapena, 1984;Otto, 1988). The ball moves down the right side of the ring toward low point. The angle between the hips and shoulders will diminish as the athlete returns to low point (Bosen, 1984). The impulse provided by the athlete along with gravity will speed the ball to optimal velocity levels for the turn (Bondarchuk, 1982). As the ball passes low point, the athlete makes a second change from double support into single support leading to the second turn. The second, third, and fourth turns follow similar movement patterns as turn one with double support occurring later with each (Gutierrez, et al., 2002;Otto, 1988). In each subsequent turn, the angle of orbit and speed continue to increase as well (Dapena, 1984;Dapena, et al., 1989).

At the top of the fourth turn, the athlete returns to the last double support of the throw. The ball is traveling toward the right side of the ring. The ball is pulled down toward low point with the athlete's right side. As the ball reaches low point, the athlete pivots to approximately 90° and blocks the left side by straightening the left leg (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980). The athlete drives upward with the legs and trunk first and the arms last. By giving one last pull on the hammer, the athlete has a final opportunity to add speed to the ball as it passes around the left side of the ring (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980). The implement is released into the sector at approximately shoulder level thereby completing the throw (Dapena, et al., 2003;Dapena, et al., 1982).

Comparisons are made frequently between performance levels based upon sex (Alexander, et al., 1996;Baronietz, et al., 1995;Ransdell, et al., 1999). Each sex has characteristics contributing to success within their particular sport or event (Ransdell and Well, 1999, Alexander, 1996 #63). Hammer throwers need to be strong and explosive like the other throwing events; however they must be technically sound due to the complexity of the event. Distinct anthropometric differences occur between the sexes throwing the hammer that likely affect optimal technique. The most visually noticeable differences are height and mass differences. Male hammer throwers are typically taller and have more mass than their female counterparts (Hay, 1993). A difference in implement weight affects the amount of force needed to overcome inertia and the athlete's ability to balance against centripetal forces (Hay, 1993). Men being larger and throwing a heavier implement, weighing 7.26 kg compared the women's 4 kg, overcome and withstand larger amounts of inertia and centrifugal forces to achieve a throw (Hay, 1993;I.A.A.F., 2006). Women are quicker overall at the start of the throw due to less body mass, shorter stature, and a lighter weight ball (Baronietz, et al., 1997).

The location of the center of mass of the thrower-hammer system will be different between sexes due to the different body weights and implement weights. Center of mass location for the thrower is different between sexes due to differences in weight and mass distribution (Hay, et al., 1995;Knudson, 2003). Location of the center of mass of the hammer-thrower system will also be different due to positions utilized by the sexes throughout the throw. Women are more upright during the throw due to smaller body mass and a lighter implement (Hay, 1993). Less energy is used by women to counter the forces acting upon them as men due to the lighter ball, lighter body weight and the higher center of mass than men (Hay, 1993;Knudson, 2003). Men sit lower to counter the greater forces placed upon the system (Hay, 1993).

The scientific literature has focused predominately on the characteristics of male throwers (Dapena, 1984;Dapena, 1986;Dapena and Feltner, 1989;Dapena, Gutierrez-Davila, Soto and Rojas, 2003;Dapena, et al., 1989;Dapena and Teves, 1982;Depena, 1985). Literature on female throwers has been limited to anthropometric data, performance information, and case studies (Barclay, 2000;Baronietz, Barclay and Gathercole, 1997). No literature has statistically compared the differences between the throwing technique of male and female hammer throwers. Also, the literature has not explored the technique differences affecting distances thrown. The purpose of the research was to probe for possible technique differences in sex and distance thrown.

METHODS

Subjects for this study were the top finishers in the Men's and Women's Hammer Throw at the 2003 USA Track and Field National Championships (USATF) in Palo Alto, California (6 males and 7 females) and the top finishers in the Men's and Women's Hammer Throw at the 2003 IAAF World Athletic Final, Szombathely, Hungary (8 males and 8 females). The University IRB board waived the need for informed consent since the video taken at these meets is considered public domain.

We placed and manually focused three digital video cameras (Canon model ZR40, Canon, USA) prior to calibration of the square. The cameras filmed independently from one another. A sound impulse was implanted on the video tape of each camera via a wireless transmitter (Model UC1-UA, Shure, Inc., Niles, IL) and trigger on Camera 1 to ensure the ability to synchronize the throw clips for later digitizing. Cameras 2 and 3 had RF receiver units (Shure UP4m UA 782-806 MHz, Shure, Inc., Niles, IL) attached to the audio input jack to receive the impulse.

A large rectangular space surrounding the throwing ring was calibrated using a theodolite (DGT10, CST/berger, Wateska, IL) and four 2.43-meter poles. The theodolite was placed and remained until all the poles were surveyed and filmed. Theodolite readings input into an Excel spreadsheet (Microsoft® Excel 2002, Microsoft Corp., Redmond, WA) calculated the azimuth readings to the pole locations. The calibrated area was filmed for 10 seconds. The calibration footage was used to set up the calibration parameters in the Peak Motus 8.2 system (Peak Performance Technologies, Inc., Centennial, CO, USA). The video cameras remained in place until after the post competition calibration filming of the area.

A 24-point model of the thrower was used to represent the hammer-thrower system. The best throw of each of the 29 athletes was captured and imported into the Peak Motus system. Useable information from the 2003 USA Nationals included three cameras while the 2003 IAAF World Athletic Final included two cameras, due to the third camera's movement from its calibration position during competition.

The movement of camera at the World Athletic Final prompted a study to investigate the reliability of a known velocity captured with 2 cameras vs. 3 cameras. There was no difference in digitizing reliable data whether using 2 cameras vs. 3 cameras.

All throws for each athlete were filmed. The filming occurred from the beginning of the winds through release. The best throw of each athlete was then selected to be digitized for the study. Digitization began when the athlete was centered on both feet at the beginning of the second wind. A list of variables of interest can be found in Table 1. The variables investigated were chosen based upon previous research and from knowledge of the event.

Data Analysis

Conventional descriptive statistical methods were used to calculate means and standard deviations. *T tests* were used to distinguish the differences between sexes. General linear model analysis of variance was used to test for the differences in performance variables. Statistical significance level was set at p = 0.05 level. Since the study was exploratory in nature, variables up to the p = 0.10 level were considered for discussion and should be researched at greater length to determine scientific relevance. A stepwise linear regression was run for both studies to determine if any variables were significant when compared to each other.

RESULTS

Sex Differences Study

Many variables were significant between sexes (Table 2, $p \leq 0.05$). Men were heavier and taller than women. The angle of separation between the shoulders and hips were greater at the beginning of double support of turn two, and the release velocities were greater for men. The location of the hammer head in the y direction at low point in turns two and three was greater for women. The time duration for turn one and the time within phase for double support of turn one were greater for men. The turn ratio in turn two was greater for women. Turn ratio is a comparison of single stance to double stance. The amount of centripetal force that developed in all phases of the turn except single support of turn two was significant.

Table 3 contains the results of the two-sample *t tests* for means between sexes, where nearly significant *p* values between 0.05 and 0.10 were observed. Height of release and the turn ration in turn one were greater for females. The total time of the throw, the amount the thrower's COM traveled in the x-y direction, the height of the swing hip in turn four, the minimum radius length in turn four, and the angle if separation between shoulders and hips in single support for turn four were greater for men.

Performance Differences Study

Many of the variables that were significant between the sexes also impacted the distance thrown. Several variables that predict success in hammer throwing distance were significant (see Table 4). The anthropometric measurement of athlete mass contributes to greater throw distance. Release velocity predicted throwing distance very well ($R^2 = 0.64$, $p < 0.$) Greater throwing distances were obtained with smaller minimum radiuses in turn two, greater maximum radius length in turn two, and greater changes in the length of the radius in turn two and four. A separation angle that was less between the shoulders and hips at double support of all turns and single support of turns three and four led to further throws. Greater separation angles between the shoulders and hammer head for single support of turn two and double supports of turns two and three led to further throws.

A stepwise linear regression was run to determine which of the variables impacted throw distance.

DISCUSSION

The results of our analysis resulted in many significant variables. We have selected the few variables that we feel have greater importance in throwing success. The variables of interest are: release velocity, release height, time, center of mass movement, shoulder to hip angle, and shoulder to hammer angle.

Sex Differences Study

Extra body mass and increased athlete height in males is an advantage to throwing distance. These two variables impact the throwing variables of velocity and release height (Hay, 1993). Subjects achieved an average release velocity of 29.2 m/s for males and 27.5 m/s for females. This matches differences between sexes previously reported as 26.2 m/s and 24.5 m/s for males and females, respectively (Hunter, et al., 2003). The greater velocities in our subjects are mainly due to the greater throwing distances in our subject pool. The extra body mass males have allows them to counter more effectively in order to generate greater angular momentum while maintaining balance as the throw progresses toward release. Based upon previous study (Hunter and Killgore, 2003) and our results, males are able to generate a velocity of release greater than females even though they throw an implement of greater mass (7.26 kg for males and 4.00 kg for females).

Increased athlete height allows a greater release height which slightly increases flight time for men (Hay, 1993). Males were taller than the females and had a greater release height in our study. This is similar to shot putting where males have a greater release height than females (Alexander, Linder and Whalen, 1996). The greater release height is determined largely by anthropometrics (Hay, 1993). The result of this increased release height is a slightly longer throw assuming all other factors are maintained.

The distance the center of mass of the thrower traveled across the ring was significant between sexes as shown by our results. Male subjects traveled an average of 1.56 meters in comparison to the average 1.37 meters female subjects moved. The ability to improve on the movement across the ring among male throwers will be hard since throwers already release at the front of the ring (Dapena, 1984). However, females may have some room for improvement in using the entire ring. Increasing the distance the center of mass travels across the ring has a meaningful effect upon the measured distance of the throw (Dapena, 1986).

Time variable results provide an interesting picture regarding overcoming of inertia and build up of centripetal force. Male shot putters are able to generate a throw in less time than females despite throwing a heavier implement (Alexander, Linder and Whalen, 1996). Male shot athletes deliver the shot in 0.4 seconds compared to 0.45 seconds for a female (Alexander, Linder and Whalen, 1996). However in hammer throwing, velocity build up is more gradual (Black, 1980;Bondarchuk, 1982;Dapena, 1984;Woicik, 1980). The average overall time of throw among subjects was shorter for women (2.07 seconds) than men (2.22 seconds). In a time comparison of turns 1, male subjects in our study took an average of 0.72 seconds compared to the an average 0.64 seconds for turn one for female subjects and within that turn the time duration for double support accounted for a time difference of 0.08 seconds between sexes. The greater mass of male hammer subjects and their implement would help account for the difference in total throw, turn 1, and double support times since they must overcome a greater amount of inertia to initiate the throw. The results suggest the extra 0.08 seconds in double support of turn one enables male throwers to impart a longer torque period thereby increasing angular momentum. Male subject turn ratio for turns one and two was smaller than the women's. The turn ratio variable compares the amount of time the athlete spent in single support to the time spent in double support. The turn ratio relationship results further supports the idea of longer torque application on the hammer during the double support phase for males during the first two turns.

Performance Differences Study

Athlete body mass impacts the distance thrown as the hammer results show. A heavier thrower has the ability to throw farther (Hay, 1993). However, other factors must still be considered. Velocity at release is the most important factor in determining the distance of a throw (Bosen, 1984;Dapena, 1984;Hay, 1993;Payne, 1980). The average release velocity was 28.3 m/s across all throwers. Parameter estimates predict that for every one m/s increase in velocity an extra 1.39 m can be produced. The key is to creating the extra throwing distance is a longer torque application period in double support (Bosen, 1984;Gutierrez, Soto and Rojas, 2002). The heavier implement thrown by men along with their greater masses creates larger amounts of inertia in the system (Hay, 1993). The larger inertial forces allows for a longer torque application period resulting in an increased velocity.

Coaching literature discusses the importance of an appropriate radius length of the hammer path is a concern of throwers and coaches (Black, 1980;Bondarchuk, 1982;Dapena and Feltner, 1989;Payne, 1980;Woicik, 1980). The length of radius fluctuates throughout the turns due to the pulling ahead and behind the hammer due to the movements of the athlete as they change posture during the turns (Dapena and Feltner, 1989) to accelerate the ball and counter the centripetal forces which increase throughout the throw. Among our subjects showed that the location of when the minimum and maximum length of the radius occurred did not matter. The important factor was the magnitude of change between the two lengths. Parameter estimates revealed that the minimum and maximum radius length of the hammer path in turn two were significant and can add to throwing distance if done correctly. A look at the means showed the difference in the change between the minimum and maximum radius length decreased with each turn. The trend through the mean radius of the four turns saw the minimum radius of the hammer path lengthen and the maximum radius shorten as the throw progressed toward release until double support of turn four. The longer radius allows the thrower to turn slower to increase the angular momentum of the system during double support (Dapena and McDonald, 1989). The radius shortens when the centripetal forces are great enough that the upper body needs to work to help counter the hammer (Dapena and McDonald, 1989). The maximum length of the radius our athlete's developed during double support of turn four increased compared with earlier turns as the athlete was attempting to add as much angular momentum to the system as possible prior to release. The oscillation of the radius increases the momentum of the ball at a crucial time during build up of angular momentum (Hay, 1993).

Timing issues have been discussed in the coaching literature (Bondarchuk, 1980;Bondarchuk, 1982;Bosen, 1984). Throwers are grouped in to four different categories as per the timing of foot take off and landing (Bosen, 1984). Timing of take off and landing is felt to be critical to throwing success (Bondarchuk, 1980;Bondarchuk, 1982;Bosen, 1984). Turn four timing was important to throwing success among our subjects. Parameter estimates predict the longer an athlete spends in turn four, throwing distance is potentially lessened. At this point of the throw, the athlete should be moving the fastest, have the greatest centripetal force, and needs to continue moving toward release as quick as possible (Black, 1980;Bondarchuk, 1982;Woicik, 1980). Slowing momentum will decrease the distance of the throw (Hay, 1993). A possible error that may occur is an early blocking during the final effort. Blocking occurs when the athlete straightens the left leg during double support and he/she leans back to lift the hammer toward release (Black, 1980;Bondarchuk, 1982;Woicik, 1980). Both have the potential to decrease throwing distance (Bondarchuk, 1982).

Blocking occurs during the final effort in the throw (Bondarchuk, 1982). If an athlete blocks too soon, he or she essentially puts on the brakes, and loses the build up of momentum they worked for over the duration of the throw (Hay, 1993). The athlete turns with bent knees until double support of the fourth turn (Bondarchuk, 1982). At this point, the athlete gradually straightens the left leg and begins to lift the ball by uncoiling the upper body (Bondarchuk, 1982;Woicik, 1980). The final effort transfers the momentum developed by the thrower's body to the hammer (Hay, 1993).

Changes in the movement of the center of mass of the thrower and the system affected the throw positively and negatively amongst our subjects. Throwers who move across the ring in a more anterior-posterior direction can decrease throw performance. By moving in a more direct anterior-posterior movement, the thrower does not make full utilization of the ring decreasing the distance of the throw due to lesser forces being developed and exerted on the male throwers (Dapena, 1986). The athlete does not have the centripetal forces to counter against to help in the increase of the throw to maximum velocity (Dapena, 1986;Hay, 1993). However, parameter estimate results predict a thrower utilizing a greater displacement in the medio-lateral direction can increase the distance of the throw. But, the combination of movement in both directions is important in throwing distance when looking at the thrower-hammer system among our subjects. The slightly trochoid movement of the system center of mass for male throwers is the result of the centripetal acceleration of the system pulling in the positive anterior-posterior direction (Dapena, 1986). Our subjects can increase throwing distance 0.03 m for every 0.01 m of the positive y side of the ring utilized. Movement of the male hammer-thrower system in the medio-lateral direction is due to opposing masses rotating around an axis (Dapena, 1986).

Angles of separation in the hammer throw have been discussed in coaching literature but not researched (Otto, 1988). The angle of separation between the shoulders and the hammer is the angle formed between the shoulders as it intersects with an imaginary line from the hammer head. Our subjects indicate the angle of separation between the shoulder and hammer is important to throwing distance. Information from this particular angle gives position of the hammer head in relation to shoulders along with thrower potential to increase the velocity of the hammer head as single ends and double support begins. The mean angle of separation of our subjects oscillated to slightly greater than 90° during single support of each turn to 108° during double support. Subject angle of separation were similar to those of Otto (1988). However, he reported results showing the hammer head moving ahead of the thrower during the throw (Otto, 1988) something our subjects didn't achieve. The separation angle during the double support phase of turns two, three, and four for our subjects has varied impact on increasing the distance of the throw. Turn two had a separation angle of 97.6° and a range of 71° to 136°. The mean separation angle for turns three and four was 104° for our subjects. The subject angle ranges were similar for both with a shoulder separation angle range of 71° to 127° and 66 to 128° for turns three and four, respectively. Turn four, shoulder to hammer separation angle, had the greatest possible impact by possibly adding 0.2 m to a throw for every angle versus the 0.15 m for turn two and 0.19 m for turn three among our subjects. An optimal angle for shoulder to hammer head separation has not been determined and would be an area for further research.

The angle of separation between the hips and shoulders tells how well the athlete opens and closes the hips and shoulders as the throw progresses. The benefit of the separation angles may allow for a greater increase of angular momentum during double support. An increase in torque and time are required for increasing angular momentum, throwers will benefit from a greater angle of separation as they come to double support (Hay, 1993). Our study revealed that the angle between the hips and shoulders was an important factor in determining distance thrown throughout all turn phases with the exception of single support in turns one and two. The mean angle of separation from our study ranged from 9° in single support of turn 1 to the largest angle of separation of 29° in double support of turn two. Otto (Otto, 1988) reported a range from 0° to 55° which our subjects fell within. If the angle of separation between shoulders and hammer head is present, the separation between the hips and shoulders is not needed and could hurt throwing distance among our subjects. By opening both angles of separation, the subjects place themselves in a position where torque application is not optimal due the radius of the hammer path becoming too short. Throw distance could be decreased between 0.14 m and 0.18m according the parameters estimates. By looking at the relationship between the two different angles of separation of our subjects, the separation between the shoulders and the hammer is large enough during double support that the separation between the shoulders and the hips is not needed to accelerate the hammer head effectively. The important concept is the location of the hammer in relation to the body.

The angle of separations between the shoulders and the hammer and the shoulders and the hips are crucial to throw success. The athlete will be able to apply appropriate levels of torque to the hammer as the proper separation occurs. Proper torque application will add to the angular momentum needed to increase throwing distance. The results of our exploratory study do point toward areas of further investigation. The affect of separation angles on throwing distance and center of mass movement may provide better insight into hammer throw improvement.

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Table 1. Listing of variables of interest

- Athlete height
- Athlete mass
- Height of swing foot within each turn
- Height of swing hip within each turn
- Velocity at release
- Height of release
- Angle of release
- Orbit azimuth in the x-z direction within each turn
- Time
    - Total time of throw
    - Total time for each turn
    - Total time with each phase of turn
    - Turn ratio
- Radius of hammer path within each turn
    - Maximum length
    - Minimum length
    - Average length
    - Change in length
- Center of mass of the system
    - height change
    - distance traveled
    - angle traveled
- Center of mass of the thrower
    - height change
    - distance traveled
    - angle traveled
- Angle of separation between the shoulders to hips within each turn
- Angle of separation between the shoulders and hammer within each turn

Table 2. Descriptive statistics for the sex comparison with a significance level of *p* = <0.05

Variable	Men (n=14)			Female (n=15)				
	Mean	SD	Std. error	Mean	SD	Std. error	*t* statistic	*p* value
Athlete Mass (kg)	112.9	13.00	3.48	86.7	12.89	3.33	5.429	<.0001
Athlete Height (m)	1.9	0.06	0.02	1.8	0.07	0.02	5.586	<.0001
Release Vel (m/s)	29.2	1.38	0.37	27.5	1.15	0.29	3.446	0.0019
Height of Swing Hip (m)								
Turn 1	0.77	0.06	0.02	0.07	0.09	0.02	2.121	0.0433
Low Point of Hammer Head – Y (m)								
Turn 2	-0.19	0.31	0.08	0.06	0.33	0.08	-2.198	0.0367
Turn 3	0.33	0.24	0.06	0.54	0.26	0.07	-2.274	0.0311
Time for Turn (sec)								
Turn 1	0.72	0.10	0.03	0.64	0.08	0.02	2.407	0.0232
Turn Ratio								
Turn 2	1.03	0.10	0.03	1.24	0.36	0.09	-2.112	0.0441
Time in Phase (sec)								
DS 1	0.39	0.08	0.02	0.31	0.07	0.02	2.515	0.0182
Angle between the Shoulders and the Hips (deg)								
DS 1	29.88	15.72	4.20	14.57	8.99	2.32	3.246	0.0031
Centripetal Force (KN)								
SS 1	11.2	5.8	1.6	6.1	1.5	0.39	3.249	0.0031
SS 2	17.9	8.1	2.2	9.1	2.2	0.57	4.070	0.0004
DS 2	19.1	8.5	2.3	10.6	3.1	0.82	3.619	0.0012
SS 3	23.3	8.6	2.3	11.7	2.8	0.73	4.986	<.0001
DS 3	23.2	9.4	2.5	12.1	1.7	0.43	4.509	0.0001
SS 4	26.7	8.8	2.4	13.2	1.7	0.47	5.436	<.0001

Table 2. (cont'd.)Descriptive statistics for the sex comparison with a significance level of $p = <0.05$

Variable	Men (n=14)			Female (n=15)				
	Mean	SD	Std. error	Mean	SD	Std. error	*t* statistic	*p* value
DS 4	24.5	9.4	2.5	13.8	2.9	0.80	3.968	0.0005

Table 3. Descriptive statistics for the sex comparison with a significance level of between $p = 0.05$ and 0.10

Variable	Men (n=14)			Female (n=15)				
	Mean	SD	Std. error	Mean	SD	Std. error	*t* statistic	*p* value
Height at Release	1.14	0.41	0.11	1.41	0.33	0.09	-2.005	0.055
Total Time	2.22	0.18	0.05	2.07	0.23	0.06	1.89	0.0696
Throw COM travel	1.56	0.12	0.03	1.37	0.20	0.05	3.016	0.0055
Height of Swing Hip								
Turn 4	0.79	0.05	0.01	0.76	0.05	0.01	1.831	0.0790
Minimum radius of hammer								
Turn 4	1.38	0.15	0.04	1.23	0.27	0.07	1.826	0.0799
Turn Ratio								
Turn 1	0.89	0.12	0.03	1.11	0.46	0.12	-1.807	0.0819
Shoulder to Hip Angle								
SS 4	32.38	33.93	9.07	14.37	10.47	2.90	1.832	0.0788

Table 4. Descriptive statistics for the distance comparison with a significance level of between p = <.0001 and 0.01

		Parameter Estimate					
Variable	β_0	$\beta_1 sex$	$\beta_2 IV$	$\beta_3 sex{*}IV$	r^2	F value	p value
Mass (kg)	100.20	-20.17	-0.22	0.07	0.71	20.41	<.0001
Release Vel (m/s)	35.16	-6.03	1.39	NA	0.64	22.60	0.0357
Change Thrower X	78.94	-9.47	-10.60	4.39	0.65	15.12	<.0001
ChangeThrower Y	42.25	22.35	18.33	-17.28	0.69	18.50	<.0001
COM sys traveled	62.97	152.21	3.43	-141.36	0.61	13.22	<.0001
Angle COM sys	81.88	-0.21	-12.35	0.12	0.69	18.59	<.0001
Change System X	81.72	-159.66	-11.98	90.51	0.65	15.31	<.0001
Height of Y Low Point							
Turn 1	80.17	-12.87	7.26	-7.33	0.59	12.21	<.0001
Turn 2	76.89	-9.46	6.09	-7.88	0.59	12.40	<.0001
Height of Y High Point							
Turn 1	58.51	21.42	6.88	-11.91	0.61	13.13	<.0001
Turn 2	52.66	25.60	8.58	-12.65	0.63	14.21	<.0001
Turn 3	41.47	35.37	11.66	-14.884	0.64	14.83	<.0001
Turn 4	47.91	39.31	8.52	-14.488	0.62	12.28	<.0001
Height of Low Point Z							
Turn 1	81.02	-16.15	-17.13	26.579	0.62	13.43	<.0001
Turn 2	80.62	-13.67	-22.80	25.121	0.62	13.54	<.0001
Turn 4	78.02	-8.60	-23.65	NA	0.58	16.67	<.0001
Minimum Length of Hammer Radius							
Turn 2	95.12	-28.80	13.94	14.738	0.63	14.02	<.0001
Turn 4	100.53	-34.27	-18.02	19.294	0.64	13.41	<.0001
Maximum Length of Hammer Radius							
Turn 2	56.08	14.48	9.025	-10.504	0.63	13.85	<.0001

Table 4. (cont'd.)Descriptive statistics for the distance comparison with a significance level of between p = <.0001 and 0.01

		Parameter Estimate					
Variable	β_0	$\beta_1 sex$	$\beta_2 IV$	$\beta_3 sex*IV$	r^2	*F* value	*p* value
Radius of Hammer Path							
DS 1	90.84	-23.82	-9.68	9.89	0.62	13.86	<.0001
DS 4	80.26	-8.76	-2.55	0.22	0.60	11.53	<.0001
Change in Length of the Radius							
Turn 2	69.94	7.39	-1.87	-8.188	0.65	15.62	<.0001
Time within a Turn							
Turn 4	96.97	-39.33	-45.72	69.457	0.73	20.30	<.0001
Time within Phase of Turn							
DS 4	87.26	-22.12	-47.52	59.04	0.63	12.94	<.0001
Angle between the Shoulder and the Hammer							
SS 2	60.05	-2.37	0.15	-0.06	0.65	15.24	<.0001
DS 2	56.14	17.82	0.19	-0.25	0.69	18.35	<.0001
DS 3	54.34	8.51	0.203	-0.16	0.71	20.07	<.0001
Angle between the Shoulder and the Hips							
DS 1	78.01	-13.63	-0.08	0.29	0.63	13.87	<.0001
DS 2	79.50	-15.65	-0.14	0.26	0.63	14.38	<.0001
SS 3	72.78	-8.26	0.17	-0.02	0.62	13.81	<.0001
DS 3	80.28	-13.99	-0.18	0.23	0.66	16.28	<.0001
SS 4	77.12	-11.53	-0.05	0.21	0.61	12.19	<.0001
DS 4	69.47	-5.20	0.048	-0.02	0.66	15.05	<.0001

Table 4. (cont'd.)Descriptive statistics for the distance comparison with a significance level of between p = <.0001 and 0.01

		Parameter Estimate					
Variable	β_0	$\beta_1 sex$	$\beta_2 IV$	$\beta_3 sex*IV$	r^2	*F* value	*p* value
Centripetal Force							
SS 1	82.71	0.001	-8.18	-0.001	0.80	34.17	<.0001
DS 1	82.71	-0.001	-14.66	0.001	0.75	24.58	<.0001
SS 2	83.89	-0.001	-9.63	-0.0002	0.80	33.61	<.0001
DS 2	83.85	-0.0004	-12.33	0.000	0.78	28.89	<.0001
SS 3	86.20	-0.0005	-16.20	0.0002	0.78	29.80	<.0001
DS 3	84.98	-0.0004	-9.33	-0.0003	0.78	30.31	<.0001
SS 4	86.93	-0.0004	-20.43	0.0005	0.77	25.09	<.0001
DS 4	83.40	-0.0003	-11.34	0.00001	0.69	17.12	<.0001

NA = The sex term in the Interaction was highly significant. The terms were re- run without the interaction to see what was significant in the equation.

Appendix A: Prospectus

Chapter 1

Introduction

The hammer throw is said to have its roots in Scotland and Ireland history. Folklore claims an Irish hero named Cuchulain whirled a chariot wheel with an axle attached to it around his head and released it as the first person to throw a hammer (Black, 1989;Dziepak, 1998). People are familiar with the Scottish Highland Games where events like the sheaf toss, weight throw for distance, and tossing the caber are the events and highlight the strength and power of the participants.

Another competition at these games finds men throwing the working sledge hammer or long hammer (Black, 1989). The long hammer is a metal ball attached to a 3/8" x 4 foot-long wooden handle (see Fig. 1). The predecessor to this implement was a quarry rock attached to varying lengths of wooden handles (Black, 1989;Dziepak, 1998). Organizers eventually made a standard for the length of the hammer handle. The event evolved and split into two different forms: the working sledge hammer throw and the modern hammer. Both forms continue today. The modern hammer currently is thrown currently at all levels of track and field. The modern hammer throw first appeared in the 1900 Olympics for men, but Women's hammer throw was not introduced to the sporting world until 1995. Women's hammer throw was finally included in the World Track and Field Championships in 1999 and the Olympics in 2000.

The modern hammer throw is a track event entailing speed, power, and control. The goal of the event is to throw the hammer the farthest distance possible while maintaining the rules governing the event. A throw is built upon four components, each part being equally critical to the success of the throw (Woicik, 1980). A throw is accomplished by performing a series of winds, an entry into the turns, followed by three to four turns, ending in the release of the implement. Athletes alternate between single- and double-foot support as they move through the turns of the throw (Black, 1989). Errors in any of the four components negatively affects the distance the implement is thrown (Woicik, 1980). Proper technique is crucial to each throw. The hammer is not an implement that can be "muscled" to achieve good distance.

Understanding hammer throw technique and implement modifications helped to improve distances. One of the biggest improvements was the addition of turns during the event. Turns were introduced by A.J. Flanagan in the 1890's (Black, 1989). Prior to the introduction of turns, athletes delivered the hammer from a stationary position using a figure-eight or overhead motion to throw the hammer (Black, 1989;Dziepak, 1998). Throw distance increased dramatically as a result of the revolutionary addition of the turns. The wire hammer was legalized in 1896 (Dziepak, 1998). And, the last modification was the addition of a ball-bearing swivel to a lead ball (Black, 1989;Dziepak, 1998).

Equipment modifications improve performance results only so much. In reality, the ultimate success in athletics is defined by who is able to run the fastest, jump the highest, or throw the farthest. Science tells us there are specific factors helping determine success in any event. These factors are anthropometric and technical skill qualities occurring in the right combinations for the athlete. Anthropometrics are the physical characteristics including: segment length, segment weight, overall height, and overall weight unique to each individual. Technical skill refers to the athlete’s ability to learn and develop the proper skill to perform any activity. Athletes may have the ideal physical requirements but may not be able to master the technique and vice versa. Technique and equipment improvements have helped to establish the current world records. Current world records in the hammer throw are as follows: 86.74 meters by Yuriy Sedykh in 1986 for the men and 77.41 meters by Tatyana Lysenko in 2006 for the women.

Comparisons are made frequently between performance levels based upon sex. Each sex has characteristics contributing to success within their particular sport or event. The gap occurring between sex performance levels is decreasing in most sports (Ransdell and Well, 1999). For females, sex specific characteristics are helping to narrow the performance level gap (Alexander, Linder and Whalen, 1996;Ransdell and Well, 1999). Females possess characteristics that do provide a benefit to performance improvement unique to their sex.

Powerlifting is a male dominated sport. The male sex is genetically stronger and more capable of lifting heavier weight. Men become proportionally stronger as individual weight or mass increases within the sex (Ransdell and Well, 1999). This may be due to a larger frame, greater muscle mass or other physiologic differences. The difference in the performance levels between the sexes increases as well when mass and weight are considered. Science has shown that males have a larger total muscle mass and a larger muscle fiber cross sectional area than women. Women may weigh the same but have more body fat than males (Ransdell and Well, 1999). These factors have a distinct effect on the ability to lift large amounts of weight. In the 52-75 kg weight class, the difference between sex performance is 10-30% in weight lifted but in the 82.5-90 kg weight class the difference is 35-42% (Ransdell and Well, 1999). Overall, male powerlifters lift 11kg/ kg of body weight while female powerlifters lift 6.75-8.93 kg/ kg of body weight (Ransdell and Well, 1999).

By analyzing specific track events, we can narrow down the specifics that give males an advantage in performance over females and vice versa. For example, speed and technique in the high jump and the long jump are essential to success in the event. The attributes that allow males to be more successful in the high jump are their taller frame and their greater muscle mass. The added height allows for a higher center of gravity and longer strides (Ransdell and Well, 1999). The greater muscle mass provides more explosiveness on the drive up to the bar (Hay, 1993). In the long jump, the greater height and muscle mass of male athletes allows for more rotary force to be generated, more drive off the board, and a faster approach on the runway, giving the males an advantage in strength and explosiveness (Ransdell and Well, 1999). These factors result in a longer jumped distance. Even though males have attributes that allow for greater performances, the performance-level gaps between sexes in the high jump and long jump are now within 15-16% of each other (Ransdell and Well, 1999).

An event considered the counterpart to the hammer throw is the shot put. Shot putters need to be strong, powerful, and technically sound. The shot is thrown by using a spinning motion or a gliding motion (Alexander, Linder and Whalen, 1996). The spinning motion style makes this event similar to the hammer throw. A study done on shot put athletes states the event has anthropometric and technique similarities between the sexes (Alexander, Linder and Whalen, 1996). Thigh segment length is the only anthropometric characteristic that is similar between the sexes (Alexander, Linder and Whalen, 1996). Technique-wise, the similarities between the sexes include the length of the glide, the height of the center of gravity at the start of the throw, the height of the center of gravity at the end of the throw, and the angle of release (Alexander, Linder and Whalen, 1996). However, men being taller, larger framed, and having greater muscle mass are at an advantage in throwing the shot put farther. The height of release, the length of the step during glide, and the velocity of the center of gravity during glide and release are greater for males as a result of the anthropometric differences (Alexander, Linder and Whalen, 1996), again giving them the advantage in distance thrown.

Hammer throwers need to be strong like the shot putters; however they must be quick and technically sound due to the complexity of the event. Distinct anthropometrics differences occur between the sexes throwing the hammer. The differences in mass and size between the sexes has a distinct relationship on hammer throw technique. The time for overall throw, distance throw, and time for each individual turn are variables anthropometric differences will affect (Baronietz, Barclay and Gathercole, 1997). Men being larger and throwing a heavier implement have to overcome larger amounts of inertia, centripetal, and centrifugal forces to achieve throw success. Men throw an implement weighing 7.26 kg. Women throw an implement weighing 3.26 kg. less than the men. The difference in implement weight does factor into the amount of force needed to overcome inertia and to balance against the centripetal forces. The men have greater differences in time for each individual turn as they progress through the throw (Bosen, 1984). Due to larger amounts of inertia, men begin slowly and increase their speed at a greater rate than women early in the throw (Baronietz, Barclay and Gathercole, 1997;Bosen, 1984;Romanov, et al., 1998). Men turn more rapidly during the last two turns than women (Gutierrez, Soto and Rojas, 2002). Women should be quicker overall from the start of the throw to the release of the hammer due to less body mass, smaller size, and a lighter weight ball. The overall change in velocity from start to release of the hammer is less for women (Gutierrez, Soto and Rojas, 2002, Romanov, 1998 #44). Women also do not have great differences between the time duration of the each turn since inertia is much less for them (Bosen, 1984;Romanov and Vrublevsky, 1998). The smaller mass of the system is the direct impacting force.

Another anthropometric characteristic is the location of the center of mass. Center of mass location for the thrower is different between the sexes due to differences in weight and mass distribution (Hay, 1993;Knudson, 2003;Kreighbaum, et al., 1996). Location of the center of mass of the hammer-thrower system will also be different due to weight and mass distribution of the thrower, different positions utilized by the sexes throughout the throw as well as the difference in hammer weight. Women throw with a more upright style during the throw due to smaller body mass and a lighter implement. It takes women less energy to develop the counter against the forces acting upon them as men due to the lighter ball, lighter body weight and the higher center of mass when compared to men (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Men sit lower to counter the greater forces placed upon the system (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996).

The three determining factors of throw success are the velocity, height, and angle at release (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). The most important factor is velocity at release (Hay, 1993). For instance, the technique used in the shot put today is aimed at increasing speed by using complimentary rotation and translation across the ring to move the shot forward at a high rate (Hay, 1993). Men typically are capable of generating more force. This allows males to increase velocity to higher levels than females (Hunter and Killgore, 2003)}. In the hammer, the ability to maintain ground contact with both feet for as long as possible will enhance the acceleration of the ball (Bondarchuk, 1980;Bondarchuk, 1982;Bosen, 1984). The ball will have a longer acceleration path which will allow for the increase in velocity to occur. Men have longer double support times in the first and third turns than women (Baronietz, Barclay and Gathercole, 1997;Baronietz and Borgstom, 1995;Romanov and Vrublevsky, 1998). Women are consistent with their time in double support (Baronietz, Barclay and Gathercole, 1997;Romanov and Vrublevsky, 1998). The added time in double support allows men to apply force for a longer period increasing velocity to higher rates than women.

The height at release of the implement will affect the total amount of time it is in the air. The higher the release point is from the ground, the longer the implement will be in the air. The increased air time will correlate to a farther horizontal distance (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Men being taller than most women will have an advantage. The extra height will allow the implement to travel further than the shorter female.

Angle of release will affect the vertical component of the throw. The optimal angle of release is projected to be 45 degrees (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). However, research has shown that it is actually lower and variable for throwing events in track and field (Hunter and Killgore, 2003;Linthorne, 2001). Shot put throwers release the implement at angles between 28 to 34 degrees (Linthorne, 2001). The average release angle for male and female hammer throwers is 36.6 degrees (Hunter and Killgore, 2003). A steeper angle will decrease the velocity an athlete can achieve (Hunter and Killgore, 2003). Males typically being taller are able to use release angles closer to the optimal 45 degree angle.

All implements are also affected by air resistance (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). The discus is the most sensitive to air resistance due to aerodynamics (Hay, 1993). Throwers determine the factors of velocity, release height, and release angle by executing the technique as best they can during the throw.

To date, no literature has compared any differences between the throwing technique of male and female hammer throwers. Also, the literature fails to look at the technique differences that separate various performance levels. The scientific literature has focused predominately on the characteristics of male throwers. Literature on female throwers has been limited to anthropometric data, performance information, and case studies. Female throwers do have characteristics that may cause differences in throwing style when compared to male throwers. The most noticeable are the differences of height and mass differences between the sexes. Male hammer throwers are typically taller and have more mass than their female counterparts. The sexes have different mass distribution. The differences in mass distribution contribute to a difference in the center of gravity between the sexes. Also, the differences between the total mass of the system, meaning the mass of the athlete and the ball, contribute to differences in the center of gravity of the system. Females throwing a 4 kg ball versus the males throwing a 7.26 kg ball (I.A.A.F., 2006) will affect the throwing style as well.

Study 1

Statement of the Problem

The purpose of Study 1 is to perform a biomechanical analysis and compare the technique used by male and female hammer throwers.

Research Question

What are the technique differences between male and female hammer throwers?

Research Hypotheses

Major questions

1. The velocity of the hammer at release will be less for female throwers than male throwers.

2. The height of the hammer at release will be lower for female throwers than male throwers.

3. The angle of the hammer at release will be smaller for female throwers than male throwers.

4. The radius of hammer path will be smaller for women, due to the shorter arm length of females when compared to males.

5. Shoulder to hip axis in the z-axis will be similar between women and men.

6. The location of the center of mass of the system (thrower and hammer) for females will be farther forward than males, but will follow the same overall measured movement pattern during the throw as males.

7. The location of the center of mass of the thrower will be further forward for females than males, but will follow the same overall movement pattern during the throw as males.

Minor questions

8. Incline of elliptical path of the hammer will be less for female throwers than male throwers.

9. The location of the center of mass of the hammer will be in the same location for females as males and will follow the same overall movement pattern during the throw as males.

10. The length of acceleration path will be of shorter duration for women than men.

11. The difference in velocity of the upper-body hammer system and the lower body will be less for women when compared to men.

12. The total duration of the throw from the beginning of turn 1 to release will be quicker for women than for men.

13. The time duration of each turn will be shorter for women than for men.

14. The time ratio between single stance and double stance in each turn for the female throwers will be similar to the males.

15. The location of the high point in reference to the y-axis in the frontal plane will be less for female throwers than male throwers.

16. The location of the low point in reference to the y-axis in the frontal plane will be less for female throwers than male throwers.

17. The location of the high point in reference to the z-axis in the transverse plane will be similar for female than male throwers.

18. The location of the low point in reference to the z-axis in the transverse plane will be similar for female than male throwers.

19. Shoulder axis to the wire in the y-axis will be similar between women and men.

20. Height of the swing foot during single support will be similar between women and men.

21. Height of the swing hip during single support will be similar between women and men.

Study 2

Statement of the Problem

The purpose of Study 2 is to perform a biomechanical analysis and compare the technique used by throwers to throw the particular distances. The study will be combine all throws into a single group.

Research Question

What are the technique differences between throwers that allows for the differences in the distances thrown?

Research Hypotheses

Major questions

1. The velocity of the hammer at release will be greater for longer distance throws compared to the shorter distance throws
2. The height of the hammer at release will be lower for longer distance throws compared to the shorter distance throws.
3. The angle of the hammer at release will be smaller for longer distance throws compared to the shorter distance throws.
4. The radius of hammer path will be similar for longer distance throws compared to the shorter distance throws.

5. Shoulder to hip axis in the z-axis will be similar for longer distance throws compared to the shorter distance throws.

Minor questions

6. Incline of elliptical path of the hammer will be less for longer distance throws compared to the shorter distance throws.

7. The difference in velocity of the upper-body hammer system and the lower body will be less for longer distance throws compared to the shorter distance throws.

8. The length of acceleration path will be of shorter duration for longer distance throws compared to the shorter distance throws.

9. The total duration of the throw from the beginning of turn 1 to release will be quicker for longer distance throws compared to the shorter distance throws.

10. The time duration of each turn will be shorter for longer distance throws compared to the shorter distance throws.

11. The time ratio between single stance and double stance in each turn will be similar for longer distance throws compared to the shorter distance throws.

12. The location of the high point in reference to the y-axis in the frontal plane will be less for longer distance throws compared to the shorter distance throws.

13. The location of the low point in reference to the y-axis in the frontal plane will be less for longer distance throws compared to the shorter distance throws.

14. The location of the high point in reference to the z-axis in the transverse plane will be similar for longer distance throws compared to the shorter distance throws.

15. The location of the low point in reference to the z-axis in the transverse plane will be similar for longer distance throws compared to the shorter distance throws.

16. Shoulder axis to the wire in the y-axis will be similar for longer distance throws compared to the shorter distance throws.

17. Height of the swing foot during single support will be similar for longer distance throws compared to the shorter distance throws.

18. Height of the swing hip during single support will be similar for longer distance throws compared to the shorter distance throws.

Assumptions

The following assumptions will guide this study:

The athletes will give their best effort for the throw analyzed.

Delimitations

This study will be delimited to

1. The top six females and the top six males as determined by order of finish at the USA Track & Field Association National meet held at Stanford University in Palo Alto, CA in July 2003.
2. The top eight females and the top eight males as determined by I.A.A.F. ranking order at the World Athletic Cup Final meet held in Szmobathely, Hungary in September 2003.

Limitations

There are currently no limitations.

Definitions

For the purpose of this study the following terms were used. All references to the hammer throw are from the perspective of a right hand thrower.

Single support phases. The athlete rotates about a single-legged support at times during the throw. For a right-handed thrower, this is the left leg. Single stance phase occurs during each of the four turns. It lasts from take-off of the right foot following double support until touchdown of the right foot going into double support stance.

Double support phase. The athlete rotates about a two-legged support at times throughout the throw. Double stance phase occurs during each of the four turns. It lasts from touchdown of the right foot after single support until take-off of the right foot at the beginning of the next turn going in to single support.

Time from beginning of turn 1 to release. Time duration in seconds from the beginning of turn 1 until the thrower releases the hammer. The beginning of turn 1 is the point of loss of contact with the ground of right foot after the entry wind. The removal of both hands from the grip of the hammer signifies the release point as the thrower goes into single support stance.

Time from turn "x" to turn "x + 1". Time duration in seconds from the beginning of one turn until the beginning of the next turn. The event that marks the end and the beginning of subsequent turns is the loss of contact with the ground of right foot.

Time ratio between single stance and double stance in each turn. A ratio determined by dividing the single stance time by the double stance time of each turn. The ratio tells us the balance between the single support phase and double support phase of each turn.

Velocity of the hammer at release. The velocity the hammer head is traveling at the time of release.

Angle of the hammer at release. The angle of trajectory the hammer head is following at the time of release relative to horizontal.

Height of the hammer at release. The height the hammer head is from the ground at the time of release.

Location of the center of mass of the system (thrower and hammer). The location of the center of gravity of the athlete and of the hammer achieved during the entire throw determined by mathematical equation. This is a combination of both the center of mass of the implement and the thrower as they progress during the throw.

Location of the center of mass of the thrower. The location of the center of gravity of the athlete achieved during the entire throw determined by mathematical equation as he/she progresses through the throw. The location of the thrower's center of mass is independent from the implement.

Location of the center of mass of the hammer. The location of the center of gravity of the hammer achieved during the entire throw determined by mathematical equation. The location of the implement's center of mass is independent from the thrower.

Radius of hammer path. The radius of the hammer path is measured from the z-axis through the center of mass of the system to the center of the ball of the hammer head.

Length of acceleration path. The length of the acceleration path is the distance the ball travels as it is increasing in velocity until the point in the turn where acceleration begins to decrease. Each turn will have an acceleration path.

Incline of elliptical path of the hammer (orbit of the hammer). The angle of incline measured in reference to the y-axis relative to the horizontal in the direction of the throw and the high point the hammer takes through each of the individual turns.

The location of the high point. The ball's location when it is at the highest point in relation to the ground during each turn. The high point is established by proper execution during the winds and is location dependent upon arm movement in relationship to the body and the ring.

The location of the low point. The ball's location when it is at the lowest point in relation to the ground during the turns. The low point is established by proper execution during the winds and is location dependent upon arm movement in relationship to the body and the ring.

Shoulder to hip axis. The angle formed between the hips and the shoulders as the athlete goes through the turns in reference to the z-axis. The angle helps to determine how far the hips and shoulders are open at key points within the turn. At beginning of single support, the hips and shoulders should be close to parallel, indicating little or no force is being applied by the thrower. At beginning of double support as the thrower “catches” the ball, the hips and shoulders should be open, indicating force is being applied by the thrower. A positive angle is defined as the line through the shoulders and is ahead of the line through the hips.

Shoulder axis to the wire in the z-axis. The angle formed between the shoulders and the cable of the hammer in relationship to the z-axis. This angle will help to indicate whether the ball is being accelerated or drug by the athlete. A positive angle is defined as the line through the shoulders and is ahead of the line through the cable.

Height of the swing foot. The vertical distance measured from the ground to the center of the foot of the elevated extremity during the single support phase. The vertical distance used will be the maximum height achieved by the swing foot. The center of the foot is determined by 50% of the distance between the toe and the heel.

Height of the swing hip. The distance measured from the ground to the center of the hip joint on the elevated extremity during the single support phase. The vertical distance used will be the maximum height achieved by the swing hip. The height of the hip is determined by the distance between the ground and the hip.

Chapter 2

Review of Literature

Description of the Implement

A ball, a length of wire, and a handle make up the hammer (see Fig. 2). The overall weight and dimensions of the hammer used in competition is different between men and women. Ball diameter varies between the sexes. Males use a ball that is between 11 and 13 cm in diameter and weighs 7.26 kg. Women throw a ball between 9.5 and 11 cm in diameter that is 4 kg (I.A.A.F., 2006). A men's hammer is between 117.5 and 121.5 cm in length. The women's hammer length must fall between 116 and 119.5 cm (I.A.A.F., 2006). The ball is composed of solid iron or other metals that are not softer than brass (I.A.A.F., 2006). The ball cannot be filled with any materials that may add to the overall weight. A looped wire is attached to the handle at one end and the ball at the opposite end. The wire measures 3 mm in diameter (I.A.A.F., 2006). The wire is one piece and can not be stretched when placed under the tension of the throw. The wire is looped at both ends securely attached directly to the handle and to the ball by a swivel (I.A.A.F., 2006). The handle is a solid piece shaped like an isosceles triangle and should not stretch when placed under the tension of a throw (I.A.A.F., 2006). The regulations also specify where the center of gravity of the implement can be located. Center of gravity is not to be more than 0.6 cm from the center of the ball and must be able to balance in the holder of a weighing device with a 1.2 cm depression (I.A.A.F., 2006).

Description of Ring and Throwing Sector

The throwing circle is 2.135 m in diameter (I.A.A.F., 2006). The ring is constructed out of a non-slippery material, typically concrete. The rim of the ring is between 14 and 26 mm above the throwing surface (I.A.A.F., 2006). The top of the rim of the circle must be flush with the surrounding ground outside the ring. The interior surface of the ring is uniformly level. For a legal throw, the hammer must land within the throwing sector after release. The throwing sector is an angle beginning at the center of the throwing circle and projecting 40° outward into the throwing area (I.A.A.F., 2006)(see Fig. 3).

Description of Event

Technique developed by hammer throwers is the result of many factors and individual effectiveness in developing the proper mechanics of the event (Gutierrez, Soto and Rojas, 2002). The hammer throw can be broken down into four phases: winds, transition, turns, and delivery (Black, 1989;Woicik, 1980). Each phase of the hammer throw has a direct effect on the phase that it precedes (Woicik, 1980). The winds are sometimes referred to in the literature as swings.

Release is also known as the delivery. The description of the throw will be given from the perspective of a right handed thrower.

Grip

Hammer throwers use specific hand and finger placements in order to throw the implement. The normal grip for a right handed thrower is a right-over-left hand hold (see Fig. 4). The thrower takes the handle of the implement in the left hand, placing the handle across the middle phalanges of the second, third, and fourth digits and grips around the handle (Bondarchuk, 1982). The implement handle crosses the fifth digit at the meta-carpal phalangeal joint during the initial grasp (Bondarchuk, 1982). The right hand comes in to place naturally. The distal end of digits two, three, four, and five of the right hand hit at the base of the meta-carpal phalangeal joints of the left hand and do not cross to the backside of the hand (Bondarchuk, 1982). The thumbs are positioned by placing the left thumb over the top of the right (Bondarchuk, 1982).

Winds

The winds initiate the throwing action of the hammer throw (Black, 1989;Bondarchuk, 1982;Woicik, 1980). Winds have a distinct effect, not only on the entry into the turns, but on the entire throw (Bondarchuk, 1982). The thrower will perform two or three winds based upon personal preference. Winds of the implement will move from right to left in an orbital manner around the athlete. Overall, the winds must be relaxed, smooth, and with a long radius. The plane of the hammer during the winds should be relatively flat (Black, 1980;Simonyi, 1980). If the plane is too high in the winds, the thrower will have a difficult time controlling hammer speed and trajectory during the turns. First, wind speed is slow and controlled (Simonyi, 1980) (see Fig. 5). A flat second wind allows the hammer to pass the back of the circle very close to the ground (Bondarchuk, 1980). The thrower will be able to control the throw much better in its entirety with the flatter angle (Simonyi, 1980) due to forces being with the ability of the athlete's strength to control. The athlete's head position to establish the correct low point remains facing toward 355° and motionless (Simonyi, 1980). Inability to control the hammer can be very dangerous for the athletes as well as officials. Any errors during the winds will create an unstable position, diminish the effectiveness of the transition into the turns (Black, 1989) and greatly affect the distance of the throw (Bondarchuk, 1982). The two main goals of the winds are to build up the centrifugal force (Woicik, 1980) and establish the orbit of the ball (Black, 1980;Simonyi, 1980). The winds also help to establish and set the rhythm, radius, high points and low points of the throw (Black, 1980;Bondarchuk, 1982;Simonyi, 1980).

The movement of the winds establishes a pendulum rhythm. This rhythm will help set the balance between the thrower and centripetal forces of the throw. Centrifugal force is the force a rotating body applies along the radius outward from the axis of rotation (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Centripetal force creates a force from the radius and directs inward to the axis of rotation (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). The centrifugal and centripetal forces are necessary to allow the athlete to balance against the force as they move through the transition and into the turns (Woicik, 1980). Athletes need the counter these forces to maintain balance of the hammer-thrower system (Bondarchuk, 1980;Woicik, 1980). The athlete must counter effectively during the high points and low points of the turns to create an impulse to balance the system and increase the velocity of the ball. Proper countering in the winds is when the ball is to the right; the hips are to the left. When the ball is to the left, the hips are to the right. Countering occurs throughout the throw. The most noticeable countering occurs during the turns where velocities are at their greatest but is developed effectively during the winds (Black, 1980;Bondarchuk, 1982;Woicik, 1980).

High point and low point are established during the winds. The proper high and low points provide for consistency in the turns and affect the angle of release (Otto, 1988). Low point occurs at approximately 0° which will be 180° from the throwing direction (Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). Location of low point depends on the movement of the ball relative to the body (Simonyi, 1980). The location of low point will be in different locations based upon the type of thrower. Early technique placed low point location slightly to the right of the thrower as they faced 355° (Simonyi, 1980;Woicik, 1980). Time and development of technique has shifted it slightly to the left. A quick turner's low point will occur off the great toe of the left foot while for slow turners it is off the great toe of the right foot (Bondarchuk, 1980). High point for the turns will move higher with each successive turn as velocity increases (Simonyi, 1980). However, uncontrolled turns will cause the low point of the ball to drift and the thrower will become unbalanced during the turns, decreasing throw distance (Black, 1980).

Air resistance does affect throw despite the weight of the implement. Air resistance against the ball starts at low levels and gradually increases as an athlete progresses through the winds and angular velocity increases (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). The air resistance to mass ratio is smaller for men than women, causing a smaller effect of air resistance for men (Dapena, Gutierrez-Davila, Soto and Rojas, 2003).

Athletes competing today typically utilize two winds before entering into the turns. The velocity established in the winds must not negatively affect the technique or the entry into the first turn (Bondarchuk, 1980). The velocity of the winds is only as fast as the athlete can handle (Bondarchuk, 1982). A too slow or too fast velocity will affect the distance thrown. The rate of speed on the first wind is not as critical as the speed of the last wind before the transition phase. The first wind is typically slow and controlled; the second is faster (Simonyi, 1980).

Throwers utilize different methods of getting the hammer moving. Stationary, dynamic, and pendulum starts are the three most commonly used. A moving start allows the athlete to utilize momentum to get the hammer moving effectively. A dynamic start allows the athlete to begin a series of unbroken motions. The athlete enters the ring with the hammer in the left hand from the front of the ring (0°/360°) and centers himself at approximately 0°/360°. With feet shoulder width apart, the left foot is placed at the ring's edge while the athlete's right foot is slightly away from the edge. Body weight is evenly distributed. The athlete swings the ball toward the back of the ring with the left hand. The ball is then swung to the right towards the front of the ring at an angle of approximately 230° in one continuous motion. The right hand now is added to the grip. This is the pendulum motion type of throw initiation.

For the first wind, the angle should be relatively flat (Woicik, 1980). Radius should be long and relaxed (Black, 1980;Simonyi, 1980). Speed during the first wind should be easy and slow (Simonyi, 1980;Woicik, 1980). The athlete remains tall and centered in an athletic stance within the orbit of the hammer. The hips and feet remain in their initial position of shoulder width, left foot at the rim and the right slightly behind. The thrower's shoulders and trunk are turned far to the right as the ball is swung to the right side. With the movement of the ball to the right side, the athlete loads the right side of the body. The left heel comes off the ground to allow greater rotation of the trunk to the right side. The athlete begins the ball moving toward the back of the ring in a curvilinear motion (Bondarchuk, 1982). The arms of the athlete are extended fully and relaxed. As the ball continues moving around the athlete and down the right side, the hips and the feet of the athlete remain facing the back of the ring. The left heel is back down onto the ground and the right heel is lifted. The athlete's weight is solidly on the right leg, helping to develop torque. The athlete continues to sweep the ball past the low point. The ball is at its lowest point as it travels to the back of the ring (Payne, 1980). The hips and the shoulders are parallel as the ball moves through the back of the ring (Bondarchuk, 1982).

As the ball passes to the front of the athlete, the athlete lowers the left shoulder to allow the hammer to continue in the circular motion to the left of the athlete. The arms of the athlete are again fully extended and relaxed to make the radius of the hammer path as long as possible (Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). The athlete continues to develop the counter with the hips. The athlete uses the weight shifting from the right to the left side to counter the developing centrifugal forces.

As the ball passes to the left side, the athlete shifts slightly to the left to load the left side (Woicik, 1980). Loading the left continues to build the counter the athlete needs to maintain their balance and speed as the centrifugal and centripetal forces increase. The ball passes up the left side and behind the athlete's head. The elbows bend and the hands barely clear the top of the head. To help accomplish the wind behind the head, the right wrist rolls over the left. The left shoulder is again slightly lower than the right as the ball moves toward the front of the ring.

Once the ball is behind the thrower's head, the thrower turns the head, shoulders, and trunk to the right as the ball reaches the high point of its path. As the hands and the hammer clear, the arms are bent at the elbows. Elbow bend helps to accelerate the ball as it moves down the right side back towards the low point when the athlete extends the arms. As the ball moves down the right side, the thrower extends the arms as quickly as possible to establish the lengthened radius and push the ball to the low point, increasing ball speed (Simonyi, 1980). The arms and shoulders are relaxed and long to help develop the maximal radius of the hammer path again (Black, 1980;Simonyi, 1980). The hips and feet remain facing in the original position. The right foot flattens to help prevent sway and build torque at the hips (Black, 1980;Simonyi, 1980;Woicik, 1980).

The second wind follows a similar motion (Simonyi, 1980). The difference between the first and second wind is the plane the ball travels in is slightly flatter and the velocity of the ball is faster than the first wind (Simonyi, 1980;Woicik, 1980). As the hammer drops to the right of the athlete from high point, the shoulders and trunk are again turned to the far right. The athlete returns to a lengthened radius as the ball moves to the back of the circle. The right heel is on the ground and the left heel is lifted. The athlete's weight is solidly on the right leg, helping to develop ball velocity and torque (Black, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). The athlete continues to sweep the ball past the low point one more time. The athlete now steps the right foot closer toward the lip of the ring and parallel to the left as the ball passes through low point. The hips and feet are still facing the back of the ring. Hips and shoulders return to a parallel position. The athlete continues to counter with the hips. As the ball passes the left side, the athlete shifts slightly to the left to load the left side. The left heel returns to the ground and the right heel is lifted. Loading the left still continues to build the counter the athlete needs to maintain the balance and speed of the system as the centrifugal and centripetal forces increase (Black, 1980;Simonyi, 1980;Woicik, 1980). The ball moves up the left side, the athlete bends the elbows and rolls the wrist to move the hands behind the head.

Transition

Transition is the phase of the hammer throw where the athlete links the winds to the turns (see Fig. 6). This phase is also critical for the success of the throw (Black, 1980). It involves perfect timing with the correct displacement of the hammer to direct the throw and maintain the long radius (Simonyi, 1980;Woicik, 1980). The transition is mastered by timing the turn and the displacement of the athlete from the erect position to a squatting position (Bondarchuk, 1980). Four movements must be synchronized for a proper transition to occur. One, the thrower sets the proper relationship and balance between the thrower and the hammer by sitting back (Black, 1980). Two, the level of mass changes both vertically and horizontally as the athlete sits back to counter forces (Simonyi, 1980). Angular acceleration of the hammer is developed toward the front as a result of the change in mass level (Black, 1980;Simonyi, 1980). Three, the athlete must maintain a maximum radius to accelerate the ball as optimally as possible (Woicik, 1980). Lastly, the correct weight shift allows the left foot to become the center of rotation for the turns (Bondarchuk, 1982).

The transition begins at the high point of the final wind. The thrower turns their shoulders and trunk far to the right and the ball is at approximately 230° and returning to the back of the ring, moving counterclockwise. Arms are being fully extended from the bent elbow position as the ball moves down the right side. The ball falls toward the back of the ring, increasing in velocity under the influence of gravity and the torque applied by the thrower (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980). The thrower uses the legs and the right arm to drive the ball from the high point to the low point (Black, 1980;Simonyi, 1980). As the ball moves toward the low point in the throw, the athlete drops from an erect position to a bent knee position, (Woicik, 1980) with the right side loaded. Vertically and horizontally acceleration occurs when the athlete drops into a squat position (Simonyi, 1980). The athlete continues to counter against the increasing forces and the increasing speed by sitting back into a squat position (Black, 1980;Bondarchuk, 1980;Simonyi, 1980;Woicik, 1980).

The athlete undergoes a shift in body weight from right to left throughout this transition to help the body turn to the left. The athlete shifts the hips and weight to the right as they push the ball to the left (Black, 1980;Simonyi, 1980). This is called a push-sit (Simonyi, 1980). The push-sit helps to increase the centripetal force and sets the thrower weight over the right foot (Black, 1980;Simonyi, 1980). A loaded right side allows for the pivot to develop on the left and helps set up the proper foot work necessary to throw the ball a maximal distance (Bondarchuk, 1980;Bondarchuk, 1982). As the ball passes the low point, weight is shifted to the left and rises to the left as the ball moves to the left side of the thrower. The athlete begins to pivot to the left on the heel of the left foot and on the toes of the right foot when the left side is loaded (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980).

Athletes use two different types of foot roll based upon their amount of experience. Beginner hammer throwers utilize a heel-toe turn (Simonyi, 1980). This type is not as efficient or quick as the second type. As the thrower becomes more experienced, the heel-toe turn is adapted to include an outer foot edge roll (Simonyi, 1980). Athletes can turn faster by stiffening the left ankle and pigeontoeing the left foot to accomplish the edge roll (Simonyi, 1980). The result is a more efficient and quicker method of proceeding through a turn.

The momentum created by the fall of the ball and the acceleration of the athlete-hammer system on the right side moving to the left allows the thrower to balance on the left, while pushing off with the right (Payne, 1980). The left foot now becomes the center of rotation when it is fully loaded. The athlete continues to push the ball to the left until it passes the low point in the orbit. The athlete must now maintain alignment with their arms and the ball (Woicik, 1980). If the ball remains behind or moves forward, the athlete is pushing or dragging. Both negatively affect the distance thrown.

The plane of the ball increases in angular orbit. As the athlete counters, the ball rises to the left and up the left side of the thrower (Black, 1980) and increases the angle of the orbit. As the ball passes the low point, the hips and shoulders should be in the same plane to conserve energy and to allow the ball to do the work. The hips and the shoulders open to a 45° angle as the athlete moves to single support (Woicik, 1980). As the athlete begins to pivot on the left heel and on the toes of the right foot, the turns are beginning. The thrower needs to maintain ground contact with the right foot as long as possible to be able to impart force on the ball (Bondarchuk, 1980;Bondarchuk, 1982).

Turns

The purpose of the turns is to create the best conditions to increase speed in body and hammer rotation (Bondarchuk, 1982;Simonyi, 1980) with the overall velocity of the hammer being increased to maximum levels at delivery (Black, 1980;Bondarchuk, 1980). Turns in the hammer throw are a series of complete revolutions of the hammer-thrower system following the winds. A turn follows the winds and is characterized by alternating between double support and single support stance (see Fig. 7) (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980).

Acceleration of the hammer, the athlete, and the system is not possible during single support stance (Black, 1980;Bondarchuk, 1982;Dapena, 1984;Otto, 1988;Simonyi, 1980). The hammer-thrower system rotates due to inertial forces during single support (Bondarchuk, 1982). An athlete loses torque-generating ability and speed during single support due to the gravitational effects and the friction between the thrower's shoe and ground (Bondarchuk, 1980;Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996;Woicik, 1980). Torque production needs to be regained as soon as the athlete can to minimize loss of velocity (Woicik, 1980). Effective acceleration in the turns occurs when there is an effective counterforce between the feet and the ground (Simonyi, 1980).

Effective acceleration depends on the athlete's actions in double support (Bondarchuk, 1982). To accomplish this, the athlete needs to regain right foot contact as soon as possible to generate more torque and increase velocity (Bondarchuk, 1980;Simonyi, 1980). The right foot plays the active role during single support stance and determines the difference between hammer speed and lower body speed (Bondarchuk, 1982). Acceleration depends on tight turning by the athlete (Black, 1980;Otto, 1988)} and the right foot being actively placed upon its return to double support to help accelerate the hammer (Bondarchuk, 1982;Simonyi, 1980). The difference between the speed of the hammer and the lower body helps minimize speed loss while creating the best conditions for greatest velocity increases (Bondarchuk, 1982).

As the athlete returns to double support, the individual imparts force on the hammer since the required components for force development are met. The art of effective turning utilizes the upper body and lower body (Baronietz, Barclay and Gathercole, 1997;Bondarchuk, 1982). The angle between the shoulders and the hips in reference to z-axis is the main component allowing torque to be generated as the athlete moves the ball from high point to low point down the right side (Barclay, 2000;Bondarchuk, 1982). The two axes are not parallel at touch-down of the right foot upon return to double support. Torque is generated by the athlete returning the hips and shoulders to a parallel position (Bondarchuk, 1982). The return of shoulders and hips in the same plane increases the velocity of the ball during double support (Black, 1980;Bondarchuk, 1980;Simonyi, 1980;Woicik, 1980).

There is no limit to the number of turns an athlete may use to accomplish the goal of the longest throw (I.A.A.F., 2006). The decision to utilize three turns or four turns is based upon athlete ability to accelerate the hammer while athletes to utilize four turns to get across the ring. Before the 1980s, throwers predominately used three turns. Coaches felt maximum speed was achieved with three turns and no athlete could handle the speed developed with four (Bondarchuk, 1980). The thrower must accelerate the ball smoothly throughout the turns (Bondarchuk, 1980;Dapena, 1984;Simonyi, 1980). The ability to increase velocity during double support is the key to success in the turns (Bondarchuk, 1982).

During the transition into the turns, the velocity of the ball is at the beginning of its route toward maximum levels. The athlete accomplishes ball acceleration by shifting weight from right to left with the lower body while using the right side of the upper body to place force on the hammer (Bondarchuk, 1982). Pulling on the hammer with the right arm will not necessarily increase ball speed (Dapena and Teves, 1982). The shifting of weight and force application of the right upper body, if done at the proper time, along with the return of the hips to parallel with the shoulders serves to accelerate the body and the hammer (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Throw success is partially determined by the difference between the thrower's body speed and the hammer's speed (Baronietz, Barclay and Gathercole, 1997;Bondarchuk, 1982). Coaches and researchers have suggested lengthening double support as a means to increase velocity and distance in performance (Black, 1980;Bondarchuk, 1982;Otto, 1988;Simonyi, 1980). The ability to accelerate during the turns does decrease due to double support occurring later and later as the thrower progresses through the turns (Bondarchuk, 1982). The athlete has less time in double support to apply force during the later turns.

The position of the athlete's center of mass height changes throughout the turns. The athlete drops to a deeper squat position in the first turn as double support is being lost. Thrower center of mass is at its lowest point during the first turn. As the thrower regains double support stance, they return to a relative squatting position that is natural and not forced (Bondarchuk, 1982). The athlete changes the center of mass vertically and horizontally with each successive turn. The athlete progressively stands more and more erect as they move through the throw (Dapena, 1986). Athletes have developed the balance, or countering, needed between the centripetal and centrifugal forces to help maintain the balance of the system (Hay, 1993). Most athletes will counter with their hips in the first two turns (Hay, 1993;Woicik, 1980). As the speed increases throughout the turns, the athlete must also counter with the shoulders to balance the increasing forces due to the hammer (Hay, 1993;Woicik, 1980).

The changing posture of the thrower affects the hammer's orbital plane. The orbit of the hammer becomes steeper relative to the ground plane as the throw progresses in preparation for a release of about 35-45˚ (Dapena, 1984). The angular momentum of the hammer-thrower system increases in magnitude and tilt with each turn (Dapena and Feltner, 1989) especially during double support (Gutierrez, Soto and Rojas, 2002). Angular momentum increases in the hammer-thrower system with a faster and steeper plane of motion(Dapena and Feltner, 1989;Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996).

The second wind is the transition set-up into the first turn. The winds generate enough momentum to allow the ball to pull the athlete to 180° as the ball passes to the low point and up the left side of the thrower. The pivot on the left heel and right toes during the transition initiates the athlete to simultaneously go from an erect to a squatting position (Bondarchuk, 1982). At this time in the first turn, the athlete lowers his center of gravity both horizontally and vertically at this time in the first turn (Simonyi, 1980). The sit performed by the athlete helps to build the counter against the forces to balance the centrifugal and centripetal forces generated by the hammer-thrower system (Woicik, 1980). Turn rotation is accomplished by the heel/toe turn counterclockwise on the left heel and the right toe (Bondarchuk, 1980;Bondarchuk, 1982). The athlete uses the left foot as the center of rotation for the turns (Payne, 1980;Simonyi, 1980;Woicik, 1980).

Again, the right foot and leg is the most active part of the system during single support (Bondarchuk, 1982). The right foot leaves its contact with the ground during each turn as the left great toe reaches approximately 170° – 180° (Otto, 1988;Simonyi, 1980). The right foot is held off the ground just above the height of the ankle, optimally at 0.3 m (Otto, 1988) away from the left shin and the right knee is close to the inner left thigh (Otto, 1988;Simonyi, 1980). The right foot is kept close to the center of rotation during single support to minimize the moment of inertia loss potentially slowing the athlete’s rotation even more in the turns (Bondarchuk, 1982;Simonyi, 1980) than the effect gravity and friction causes (Dapena, 1984). This allows the athlete to actively return to double support as quickly as possible (Bondarchuk, 1982;Dapena, 1984;Simonyi, 1980).

As the athlete approaches approximately 180°, the athlete shifts from the heel of the left foot to a roll on the outside of the left foot until the toes are in contact with the ground (see Fig. 8). As the toes of the left foot come in contact with the ground, the right foot is planted. Ideally, the right foot returning to double support should also coincide with the high point location of the ball. The high point in each turn is also the slowest point during each individual turn. The activity of the right leg as previously mentioned creates a difference between the upper and lower body speed (Bondarchuk, 1982). Right leg activity minimizes ball speed loss and creates conditions for the greatest velocity increase (Bondarchuk, 1982).

The hips and shoulders fall parallel when the ball passes through the low point during transition from the winds (Barclay, 2000). The upper body-hammer system rides the inertia to the high point (Bondarchuk, 1982). At high point, the shoulders and hips are not in line with one another (Barclay, 2000;Bondarchuk, 1982;Simonyi, 1980). The lower body is well ahead of the upper body-hammer system (Bondarchuk, 1982;Simonyi, 1980). The angle between the upper body-hammer system and the lower body will help the athlete accelerate the ball while the athlete is in double support (Barclay, 2000;Bosen, 1984).

The beginning of the double support position allows the athlete to form a block to increase torque on the system and add speed to the rotation of the hammer path (Bondarchuk, 1982;Otto, 1988;Simonyi, 1980). The angle between the hips and shoulders will diminish as the athlete returns to the low point (Bosen, 1984). Athletes want to extend double support as long as possible in order to generate maximum torque over the maximum time possible (Black, 1980;Bondarchuk, 1982;Dapena, 1984;Otto, 1988). The ball and the athlete continue to move in a counter-clockwise fashion around the throwing ring. The ball moves down the right side of the ring toward the low point. The impulse provided by the athlete along with gravity will speed the ball to optimal velocity levels for the turn (Bondarchuk, 1982). As the ball passes the low point, the athlete makes a second change from double support into single support leading to the second turn.

The second turn begins as the ball passes the low point. The hammer is at the highest velocity the system can generate (Bondarchuk, 1980;Simonyi, 1980). The athlete returns to single support in the same manner as the first turn; there is a weight shift to the left as the thrower initiates another left heel/right toe turn. Momentum is sufficient enough to carry the ball and the athlete around to the high point (Dapena, 1984). The athlete follows the same movements with the feet in the second turn as he performed in the first turn, however, double support will occur later than in the first turn (Gutierrez, Soto and Rojas, 2002;Otto, 1988). High point will move to the left due to the later returns to double support (Dapena, 1984). High point moves higher in relation to the z-axis (Simonyi, 1980). The third and fourth turns follows similar movement patterns as turns one and two with double support occurring later with each (Gutierrez, Soto and Rojas, 2002;Otto, 1988). In each subsequent turn, the angle of orbit and speed continue to increase (Dapena, 1984;Dapena and Feltner, 1989). The increase in speed and orbit causes the athlete to change countering from the hips to the shoulders and become more upright in their stance.

Release

At the top of the fourth turn, the athlete returns to the last double support of the throw. The ball is traveling to the right side of the ring. The ball is pulled down toward the low point with the right side. As the ball reaches the low point, the athlete pivots to approximately 90° and blocks the left side by straightening the left leg (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980). The athlete drives upward with the legs and trunk first and the arms last. By giving one last pull on the hammer, the athlete has one last opportunity to add speed to the ball as it passes around the left side of the ring (see Fig. 9) (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980). The last pull gives a final impulse to the implement prior to release. The athlete releases the implement at approximately shoulder level (see Fig. 10) (Dapena, Gutierrez-Davila, Soto and Rojas, 2003;Dapena and Teves, 1982).

Factors Affecting the Distance Thrown

Many factors will affect the distance of a throw. Factors can be broken down into main contributing factors and accessory factors. Three main factors determine the distance of a throw (Baronietz, Barclay and Gathercole, 1997;Black, 1980;Dapena, 1984;Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996;Payne, 1980;Woicik, 1980). Simply put, position, speed, direction, and air resistance determine hammer throw distance (Dapena, 1984;Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Position includes radius of the hammer, angle of release, and height of release (Hay, 1993). The remaining minor factors contribute to the overall success of the throw.

Height of Release

The first factor is the height of release (Hay, 1993). A higher release point from the ground is more advantageous to the athlete (see Fig. 10) (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Ideally, the athlete releases the hammer at shoulder level near the front of the circle (Dapena, 1984). The mechanics used by the athlete in the winds and turns help to determine release height (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982;Simonyi, 1980;Woicik, 1980).

The athlete is not always able to achieve shoulder height as a result of errors during the winds and turns. The relationship between vertical height of achieved at release and distance thrown is 1:1 (Dapena, 1984). For every meter of increased vertical distance, the throw will land a meter farther from the release point (Dapena, 1984). The closer the release occurs to shoulder height; the farther distance thrown (Dapena, 1984;Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996).

Athlete height helps to determine the horizontal distance of a throw when taken into consideration with the height of release, angle of release, and the speed of release. A taller athlete has an advantage over a shorter one with release height (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Because males of the sport are typically taller than the females, they have an advantage in release height. The added height allows the ball to be in the air for a longer period of time, which adds to the distance thrown (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). The closer the athlete releases the hammer to the front of the ring; the hammer will achieve a greater distance (Dapena, 1984). Again, a 1:1 ratio exists for every meter closer to the edge the farther the throw goes (Dapena, 1984). However, there is little room for improvements in the release at shoulder height and at the front of the ring due to the fact that most athletes already maximize this factor (Dapena, 1984).

Angle of release

The second factor, angle of release, determines the length of time the hammer is in the air (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Once the athlete releases the hammer, it becomes a projectile. Projectile motion follows a predictable pattern. Projectile motion can be broken down into a horizontal component and a vertical component (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). The horizontal component can be described as the velocity of an object as it travels parallel to the ground (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). An object with velocity moving perpendicular to the ground describes the vertical component of projectile motion (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996).

The resultant velocity, including the angle of release, determines the magnitude of the horizontal and vertical velocities of the projectile (Kreighbaum and Barthels, 1996). The results of a large angle or a small angle of release can have a negative impact on the distance thrown by the athlete. A large angle of release results in a greater vertical component for the throw. A low angle of release provides a greater horizontal component. Mathematically, the optimal angle of release is near 45° (Baronietz, Barclay and Gathercole, 1997;Hay, 1993;Hunter and Killgore, 2003;Knudson, 2003;Kreighbaum and Barthels, 1996). Hunter and Kilgore (2003) found the average angle of release for both sexes to 36.6°. Female throwers averaged between 36° and 40° for a release angle (Baronietz, Barclay and Gathercole, 1997). Men were more consistent in their release angles when compared to women (Hunter and Killgore, 2003). Baronietz (1997) states that for every five degrees from the optimal release angle; the distance of the throw is reduced by one meter. A flat release angle will produce a shorter throw as does a steep release angle. The possibility of hitting the ground at low point can be a factor for the release angle (Hunter and Killgore, 2003). This is an inherent danger when using a steep release angle. Ground contact can result in decreased speed or change in trajectory. The end result of ground contact is a shorter throw, a foul, or injury to the athlete. The forces are greater on a steeper throw due to an increase in inertia and angular momentum (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Some athletes may not have sufficient strength to control the throw. The athlete may lose control of the hammer. Males are typically stronger than females. The greater strength may give males an advantage of overcoming a steep release angle. Also, taller athletes have an advantage with the angle of release. A taller athlete will be less likely to hit the ground with the hammer if the release angle happens to be steep. Again, males may be at an advantage as males are typically taller than females.

Speed at release

Speed at release is considered by many to be the most important of the three main factors (Baronietz, Barclay and Gathercole, 1997;Dapena and Teves, 1982;Hunter and Killgore, 2003;Payne, 1980;Woicik, 1980). The speed at release must be the maximum speed the athlete can generate and control (Bondarchuk, 1982). Athletes start a throw from a stationary position and gradually increase the speed while they progress through the throw to the fastest possible speed (Dapena and Teves, 1982). Duration of the turn time determines the rate of ball acceleration and change in angular momentum. As the hammer moves faster, angular momentum increases (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Women tend to have a more uniform time reduction for each turn; men reduce turn time slowly at first and then become consistent (Baronietz, Barclay and Gathercole, 1997). The greater difference in velocity between the first turn and fourth turn by male athletes may allow increases in velocity to higher levels. Males typically have a larger mass and throw a heavier implement accounting for the male's decreased velocity in the early turns of a throw. Males have larger amounts of inertia to overcome in relation to women as a result. With females throwing a lighter implement and having less mass, one would think this favors the female thrower as far as speed at release. However, males average 26.2 m/s at the time of release while females achieve 24.9 m/s (Hunter and Killgore, 2003). Male mass, strength levels, and a heavier implement when compared to females may affect the ability to release the hammer at higher speeds.

Accessory Factors

Five accessory factors are instrumental in maximizing the distance thrown. These factors are important and contribute to the overall success of the three main factors. The accessory factors are the development and maintenance of an optimal radius, the development of centripetal and centrifugal forces, quick turn speed, establishment of proper high and low points, and adequate acceleration of the hammer.

First, the radius needs to be developed and maintained at optimal length (Maronski, 1991;Payne, 1980;Simonyi, 1980;Woicik, 1980). This maximal distance must be constant throughout the throw (Maronski, 1991). A relatively longer radius generates a greater speed throughout the movement (Kreighbaum and

Barthels, 1996;Woicik, 1980). The athlete extends the arms as far as possible and keeps the cable perpendicular to the shoulder axis while rotation is occurring in order to achieve the lengthened radius (Woicik, 1980).

Second, the athlete needs to develop adequate centripetal and centrifugal forces while maintaining the lengthened radius (Woicik, 1980). Countering occurs naturally as the athlete rotates. Athletes can counter with the hips or the shoulders (Payne, 1980). The exact type of counter used depends on the speed of the system, the strength of the thrower, and the experience of the thrower (Bondarchuk, 1980;Bondarchuk, 1982). Faster speed requires more force from the athlete to counter developing forces (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996). Greater forces from the system call for more strength from the athlete to keep the system stable (Woicik, 1980). Most athletes begin countering with the hips and add the shoulders as the speed increases (Payne, 1980). Countering with the shoulders brings more muscle groups action into the system and counteracts the centripetal forces (Payne, 1980).

Centrifugal force is the outward pulling force that wants to disrupt the rotational axis of the throw (Hay, 1993;Knudson, 2003;Kreighbaum and Barthels, 1996;Woicik, 1980). The athlete counters against the centrifugal force that is acting upon the system (Payne, 1980). The radius will undergo slight fluctuations as the athlete rotates and counters forces (Dapena and Feltner, 1989). Gravity and athlete movement influence these fluctuations (Dapena and Feltner, 1989). Single support phase finds the radius of the hammer decreasing due to countering with the shoulders (Payne, 1980). As the athlete returns to double support phase, the length of the radius is lengthened to further increase the velocity of the hammer (Payne, 1980). Athletes maximally shorten the radius at the end of the final turn. (Maronski, 1991). The shortening provides a large impulse to give the hammer one last acceleration component prior to release (Maronski, 1991;Woicik, 1980).

Third, athletes need to turn as quickly as possible to the return of double support while maintaining maximum radius (Woicik, 1980). To accomplish this, the athlete stays as tight in his rotations as possible (Bondarchuk, 1980;Morriss, et al., 1996). While the arms are at a relaxed and maximal distance, the lower body should be compact. The thighs and knees should be held together tightly during single stance. The feet should also be close to each other during single stance. The closer the lift foot stays to the axis of rotation, the faster the athlete can turn (Black, 1980;Bondarchuk, 1980;Bondarchuk, 1982). The athlete must maximize turn speed to gain maximum distance for the throw (Payne, 1980).

Fourth, the development of high points and low points at the proper locations help bring the hammer to an optimal delivery angle (Woicik, 1980). Low point is the point in the rotation of the hammer where the ball is closest to the ground. This occurs during double support phase, just prior to the lift of the foot. High point is the point in the rotation of the hammer where the ball is farthest from the ground. This occurs during single support phase, just prior to the landing of the right foot. The proper location of these two points help develop the proper plane (Woicik, 1980) and speed development (Simonyi, 1980) of the throw. A proper plane during the turns develops into a proper release angle.

Finally, the hammer accelerates to maximal levels at the time of release (Woicik, 1980). The only time an athlete can effectively accelerate the hammer is when torque is generated. Acceleration can only happen during the double support phase of the turn (Black, 1980;Dapena, 1984;Simonyi, 1980;Woicik, 1980). By maximizing double support, more force can be generated and the longer the athlete is able to apply torque during double support. The athlete increases angular velocity but not angular momentum unless an external torque is applied.

Athletes develop take-off and landing patterns to accomplish longer torque periods. There are four types: late lift and late landing, early lift and early landing, early lift and late landing, and late lift and early landing (Bosen, 1984). The variations in landing and lift help to lengthen the time force is applied to the hammer. An added component to the lift-landing pattern, helping in the acceleration of the ball, is the difference between the shoulder and hip axes. The difference between these axes is smaller than during single-support than the beginning of double- support. The greater separation at the beginning of double support allows the athlete to unwind and apply force (Bondarchuk, 1980;Bondarchuk, 1982;Payne, 1980). The longer double support time lasts, the more torque is applied (Bondarchuk, 1980;Bondarchuk, 1982). Hammer acceleration will occur as a result of the lengthened amount of torque application.

Hammer throw success culminates when the athlete is able to place all the factors in the right place at the right time (see Fig. 11). Athletes must have good balance, a lengthened radius, quick turning speed, and a powerful delivery to have a long throw (Simonyi, 1980). The technique must be free from or have minimal error. The throw must be rhythmic (Black, 1980). The sexes use a similar rhythmic style when the hammer is thrown (Romanov and Vrublevsky, 1998). The technique used by each individual is the result of anatomic factors, individual ability, and the factors previously discussed (Gutierrez, Soto and

Rojas, 2002). Female throwing style is similar to their male counterparts. Similarity in throwing style between the sexes is due to the fact that coaches who previously worked with males are now working with female athletes (Romanov and Vrublevsky, 1998).

Chapter 3

Methods

Design

Two studies will be conducted. These studies are observational biomechanical studies. Study 1 will compare the technique between male and female hammer throwers. Study 2 will compare the technique between all of the distances thrown.

Subjects

Subjects for this study will be the top 6 finishers in the Men's and Women's Hammer Throw at the 2003 USA Track and Field National Championships (USATF) in Palo Alto, CA. and the top 8 finishers in the Men's and Women's Hammer Throw at the 2003 IAAF World Athletic Cup Final, Szombathely, Hungary. The subject pool a total of 28 athletes (14 males and 14 females). The accurate breakdown per event will be 12 athletes (6 males and 6 females) from the USATF National Championships and 16 athletes (8 males and 8 females) from the IAAF World Athletic Cup Final. The University IRB board waived the need for informed consent. USATF has determined that video taken is considered public domain.

Instruments

Calibration tools – The space in which the athletes will be filmed will be calibrated to provide measurement capabilities for the studies. An electronic digital theodolite (DGT10, CST/berger, Wateska, IL) and (4) 2.43-meter survey poles will be used to define the calibrated area.

Synchronization Signal Transmitter – A wireless transmitter system (Model UC1-UA, Shure, Inc., Niles IL) will be used to implant an audio signal on to the video tape. Camera 1 will have a transmitter (FCC ID: DD4UC1, Shure, Inc., Niles IL) and trigger connected to the audio input connection. Cameras 2 and 3 will have receivers (Shure UP4m UA 782-806 MHz, Shure, Inc., Niles IL) connected to their audio input connections. The trigger will implant an audio signal on the video of each camera at the same time when it is fired. The audio signal will then be brought into the computer with the captured video clips. The clips will show the time difference between each camera and the implanted signal. The implanted signal on each camera will allow the video clips to be synchronized to the same location on the clip.

Cameras – Three Canon digital video cameras, model ZR40, recording at 60 Hz will be used to film both events.

Video System – Peak Motus 8.2 (Peak Performance Technologies, Inc., Centennial, CO, USA) will be used to capture throws. The throws will be digitized and some of the variables of interest will be calculated using this system.

A large rectangular space surrounding the throwing ring will be calibrated using a theodolite and (four) 2.43-meter poles. The theodolite will be placed and static until all poles have been surveyed and filmed. The theodolite measures azimuth readings for the top and the bottom of each of the four poles. These readings will be input into an Excel spreadsheet (Microsoft® Excel 2002, Microsoft Corp., Redmond, WA) that will calculate the azimuth readings to pole locations.

Three digital video cameras will be used to film the competitions. The cameras will be placed and remain in those locations until after the post-competition calibration of the area. Each competition site will have a unique camera set-up (see Fig. 12 and 13). The three digital video cameras will be manually focused to film the calibration area. The calibrated area will be filmed for 10 seconds. The footage filmed will be used in setting up the calibration parameters for the Peak system. The cameras will film all throws of each athlete. Each throw will be filmed from the beginning of the winds to after release.

The cameras film independently from one another. To ensure the ability to synchronize the throws for later digitizing, the cameras will be RF units attached to the audio input jack. The RF units are able to implant a sound on to the audio track of the digital video tape used to film the competition. A camera operator will trip the trigger. The trigger will send an impulse to all cameras during each throw. The impulse will implant a beep on the video tape.

Systems like Peak Motus 8.0 will be used in this study. They have been shown to be accurate and reliable in measuring positions (Everaert, et al., 1999;Klein, et al., 1995;Scholz, et al., 1993;Vander Linden, et al., 1992) and angles (Scholz and Milford, 1993). However, to further validate the system, a reliability study will be carried out looking at the Peak Motus system in measuring angles and velocity.

Peak Motus uses the direct linear transfer method (DLT) to reconstruct the three dimensional space from two dimensional images. DLT is simple and accurate while allowing the user great flexibility in positioning cameras in optimal locations for filming (Chen, et al., 1994). Reconstruction procedures are based on precise knowledge of both internal and external camera parameters. Internal camera parameters include lens and camera characteristics while external camera parameters deal with spatial orientation. The DLT method represents mathematical transformation between 3-D object space and 2-D image space (Chen, Armstrong and Raftopoulos, 1994;Wood, et al., 1986). The full DLT 3-D algorithm contains up to 11-16 parameters (Chen, Armstrong and Raftopoulos, 1994;Wood and Marshall, 1986).

There are two principles for DLT to be optimized. These are the co-linearity condition (that a marker point forms a straight line that passes through the camera lens focal point) and the co-planarity condition (that a marker point and any two cameras' focal points lie in a common plane). The limitations to the direct linear transformation method are the inaccuracies that can occur as points at the extremes or slightly outside of the calibrated space are analyized (Chen, Armstrong and Raftopoulos, 1994;Wood and Marshall, 1986). The best way to minimize this problem is to have well-distributed control points within the calibrated space (Wood and Marshall, 1986).

Calculations - Angles

Shoulder to hip angle in the z-axis. The angle formed between the hips and the shoulders as the athlete goes through the turns in reference to the z-axis.

z-axis = center of rotation about longitudinal axis

D_{SR} = distance from z-axis to joint center of right shoulder

D_{SL} = distance from z-axis to joint center of left shoulder

D_{HR} = distance from z-axis to joint center of right hip

D_{HL} = distance from z-axis to joint center of left hip

Θ_{SL}= angle between the line of the shoulders and the line of the hips in the transverse plane solved using Law of Cosines (EQ #1 & # 2).

$$c^2 = a^2 + b^2 - 2abCosC \tag{1}$$

$$\cos C = \frac{c^2 - a^2 - b^2}{2ab} \tag{2}$$

Shoulder axis to the wire angle in the z-axis. The angle formed between the shoulders and the cable of the hammer in relationship to the z-axis.

z-axis = center of rotation about longitudinal axis

D_{SR} = distance from z-axis to joint center of right shoulder

D_{SL} = distance from z-axis to joint center of left shoulder

D_C = distance from z-axis to center of ball

Θ_{SL}= angle between the right shoulder and the hammer cable from the z-axis, solved using Law of Cosines (EQ #1 & #2) and the Law of Sines (EQ #3 & #4).

$$\frac{SinA}{a} = \frac{SinB}{b} = \frac{SinC}{c} \tag{3}$$

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} = 2R \tag{4}$$

Calculations - Center of Mass and Thrower Related

Location and velocity of the center of mass of the thrower. The location of the center of mass (CM) of the athlete achieved during the entire throw determined by mathematical equation (EQ #5). The location of the thrower's center of mass is independent of the implement. CM locations and masses of each segment were previously determined by Zatsiorsky (1998).

M_S = mass of each segment

M_T = mass of the thrower

G_S = coordinate of the center of the segment

G_T = coordinate of the center of mass of the thrower

V_S = velocity of the center of the segment

V_T = coordinate of center of mass of the thrower

Male and female calculations are solved using EQ #5 & #6

$$G_T = \frac{\sum (G_S M_S)}{M_T} \tag{5}$$

$$V_T = \sum (V_S M_S) \tag{6}$$

Location and velocity of the center of mass of the system (thrower and hammer). The location of the center of gravity of the athlete and of the hammer achieved during the entire throw. G_H was previously calculated by Dapena (1986). This is a combination of both the center of mass of the implement and the thrower.

M_T = mass of the thrower

G_S = coordinate of the center of mass of the system

G_H = coordinate of the center of mass of the hammer

G_T = coordinate of the center of mass of the thrower

V_{SY} = velocity of the center of mass of the system

V_H = velocity of the center of mass of the hammer

V_T = velocity of the center of mass of the thrower

M_M = mass of the hammer is 7.26 kg.

M_F = mass of the hammer is 4 kg.

Male calculations solved in EQ # 7 & #8 and performed in all three axes.

$$G_S = \frac{(G_T M_T + G_H * M_M)}{M_T + M_M} \tag{7}$$

$$V_S = \frac{(V_T M_T + V_H * M_M)}{M_T + M_M} \tag{8}$$

Female calculations solved in EQ #9 & #10 and performed in all three axes.

$$G_S = \frac{(G_T M_T + G_H * M_F)}{M_T + M_F} \tag{9}$$

$$V_S = \frac{(V_T M_T + V_H * M_F)}{M_T + M_F} \tag{10}$$

Location of the center of mass of the hammer. The location of the center of gravity of the hammer achieved during the entire throw determined by mathematical equation. The location of the implement's center of mass is independent of the thrower. Center of mass of the hammer was previously calculated by Dapena (1986).

Height of the swing foot. The distance measured from the ground to the center of the foot on the elevated extremity during the single support phase solved by using EQ #11. The center of the foot is determined by the distance between the toe and the heel.

H_{foot} = height of swing foot at center of foot during single support

$$H_{Foot} = 0.5(z_{Toe} + z_{Heel}) \quad (11)$$

Height of the swing hip. The distance measured from the ground to the center of the hip on the elevated extremity during the single support phase. These data are calculated within the Motus software.

Calculations – Time

Time from beginning of turn 1 to release. Time duration in seconds from the beginning of turn 1 until the thrower releases the hammer. The beginning of turn 1 is the point of loss of contact with the ground of right foot after the entry wind. The removal of both hands from the grip of the hammer signifies the release point.

T_T = the difference between the final time and the initial time in seconds

T_E = the initial time at entry to single stance in seconds of turn 1

T_R = the final time in seconds at release, solved using EQ. #12.

$$T_T = T_R - T_E \tag{12}$$

Time from turn "x" to turn "x" - Time duration in seconds from the beginning of one turn until the beginning of the next turn. The event that marks the end and the beginning of subsequent turns is the loss of contact with the ground of right foot.

t_T = the difference between the final time and the initial time in seconds

t_I = the initial time in seconds of turn "x"

t_F = the final in seconds of turn "x", solved using EQ. #13.

$$t_T = t_F - t_I \tag{13}$$

Time ratio between single stance and double stance in each turn. A ratio determined by dividing the single stance time by the double stance time of each turn. The ratio tells us the balance between the single support phase and double support phase of each turn

R_T = the ratio between single stance and the double stance

T_{SS} = the total time of single stance in seconds

T_{DS} = the total time of double stance in seconds, solved using EQ. #14.

$$R_T = \frac{T_{ss}}{T_{DS}} \tag{14}$$

Calculations – General Hammer

Angle of the hammer at release. The angle of trajectory the hammer is the angle the hammer is traveling at the time of release.

D_H = horizontal distance of the thrown hammer

V_R = velocity of the hammer at release

V_V = vertical velocity of the hammer at release from Motus software

V_H= horizontal velocity of the hammer at release from Motus software

g = acceleration of the Earth (-9.81 m/s2), solved using EQ. #15.

$$\theta = Tan^{-1}\left(\frac{v_V}{v_H}\right) \tag{15}$$

Height of the hammer at release. The height the hammer is from the ground at the time of release. These data are calculated within the Motus software.

Radius of hammer path - The radius of the hammer path is measured from the center of rotation to the center most distance of the ball at the end of the hammer.

H_1 = first point is location of hammer coordinates in all three axes

H_2 = second point is location of hammer coordinates in all three axes

H_3 = third point is location of hammer coordinates in all three axes,

r_{HP} = radius of hammer path

θ_{H2}= angle at H2, solving with EQ #16 and 17. (See Figure 14, page 87)

$$\theta_{\mathrm{H2}} = \cos^{-1}\frac{\left(\dfrac{(H_3-H_1)^2-(H_3-H_2)^2-(H_2-H_1)^2}{2(H_3-H_2)(H_2-H_1)}\right)}{2} \tag{16}$$

$$r_{HP} = \sqrt{\frac{(H_2-H_1)^2}{2(1-\cos(H_2-H_1))}} \tag{17}$$

Incline of elliptical path of the hammer. The angle of incline measured in reference to the y-axis and the high point of the hammer takes through each of the individual turns.

θ_{IA} = incline of elliptical path of the hammer

H_{HP} = height of the hammer at the high point of turn "x" of the center of

mass of the ball

H_{LP} = height of the hammer at the low point of turn "x" of the center of

mass of the ball

Y_{HP} = location of y-axis in relation to the high point of turn "x" at the

center of

mass of the ball

Y_{LP} = location of y-axis in relation to the low point of turn "x" of the center

of

mass of the ball, solved using EQ #18.

$$\theta_{IA} = Tan^{-1}\left(\frac{H_{HP} - H_{LP}}{Y_{HP} - Y_{LP}}\right) \tag{18}$$

The location of the high point. The location the ball achieves at the lowest point in relation to the ground during the turns. These data are calculated within the Motus software.

The location of the low point. The location the ball achieves at the lowest point in relation to the ground during the turns. These data are calculated within the Motus software.

Calculations - Velocities and Acceleration

Velocity of the center of mass of the system (thrower and hammer.) The location of the center of gravity of the athlete and of the hammer achieved during the entire throw. This is a combination of both the center of mass of the implement and the thrower.

M_S = mass of the throwers segments

V_{Gi} = velocity of the coordinates of center of mass of the segments

V_{GT} = velocity of the center of mass of the thrower

V_{GS} = velocity of the center of mass of the system

V_H = velocity of the center of mass of the hammer

M_M = mass of the hammer is 7.26 kg

M_F = mass of the hammer is 4 kg, solved using EQ #19 and 20.

Male calculations

$$V_{GS} = \frac{\sum_{i=1}^{n}(M_{S_i} * V_{G_i}) + (M_M * V_H)]}{M_T + M_M} \tag{19}$$

Female calculations

$$V_{GS} = \frac{\sum_{i=1}^{n}(M_{S_i} * V_{G_i}) + (M_M * V_H)]}{M_T + M_F} \tag{20}$$

Velocity of the hammer at release. The speed the hammer is traveling at the time of release.

ω_H = angular velocity of the hammer

θ = change of angle

t = time

V_H = angular velocity of the hammer at release

r_H = radius of the hammer path, solved using EQ #21 and #22.

$$\omega_H = \frac{\theta}{t} \tag{21}$$

$$V_H = r_H \omega_H \tag{22}$$

F_{cp} = the centripetal force acting on the hammer

r_H = radius of the hammer path

ω_H = angular velocity of the hammer

m_H = mass of the hammer, solved using EQ. #23

$$F_{CP} = m_H r_H \omega_H^{\;2} \tag{23}$$

D = The distance thrown (m) (e.g. between 40 and 70m, Figure 1)

v_H = The velocity of the hammer at the moment of release (t=0)

ho = The height of release (approximately at shoulder height)

g = The acceleration of the Earth (-9.81 m/s2)

C = An estimated drag coefficient of the ball (0.42)(Dapena, Gutierrez-Davila, Soto and Rojas, 2003).A factor of the influence of air resistance on the distance thrown, solved using EQ #24.

$$D = \frac{v_H^{\;2}}{g\cos\theta(\theta\sin^2\theta^2 g h_O / v_H^{\;2}) \pm C} \tag{24}$$

Length of acceleration path. The length of the acceleration path is the distance the ball travels as it is increasing in velocity until the point in the turn where acceleration begins to decrease. These data are calculated within the Peak Motus software.

Data Analysis Procedures

Digitiznig. The Peak Motus system requires trial parameters to be set up prior to digitizing video. The trial parameters include all points of interest in the system being looked at. 24 points on the thrower and the hammer serves as the model for analyzing (see Fig. 15).

The footage of the survey poles and the calculated distances will be input into the Peak Motus program. A clip of the pole footage will be digitized to give a representation of the calibrated global space of the space surrounding the throwing ring. The poles used will be 2.43 m tall with (eight) 1-foot segments of alternating colors. The bottom, top and each transition between colors on each pole will be digitized providing 36 control points.

The best throw of each of the 28 athletes will be captured from the video tapes and imported into the Peak Motussystem. The footage from the 2003 USA Nationals will utilize three cameras. Footage from the 2003 IAAF World Athletic Final will utilize two cameras, due to the third camera being moved from its calibration position during competition. Imported footage will be cropped at the point where the athlete is centered on both feet at the beginning of the second wind. The footage will be made a trial and each point within all camera views will be digitized.

Study 1. The purpose of Study 1 will be to perform a biomechanical analysis and compare the technique used by male and female hammer throwers. A linear regression will be run.

H_0 = The technique used by hammer throwers is not affected by sex.

H_1 = The technique used by hammer throwers is affected by sex.

Explanatory variable (independant)

- sex

Outcome variable (dependent)

- velocity at release
- height of release
- angle of release
- radius of hammer path
- shoulder to hip angle
- athlete mass
- hammer mass

Model

$$\mu_{DV} = \mu + gender$$

for the 9 technique variables listed above as dependent variables (DV).

Study 2. The purpose of Study 2 will be to perform a biomechanical analysis and compare the technique used to throw the achieved distances. An ANOVA will be run to analyze the data.

H_0 = The technique used by hammer throwers does not affect the distance thrown.

H_1 = The technique used by hammer throwers does affect the distance thrown.

Dependant variable

- distance

Independent Variable

- velocity at release
- height of release
- angle of release
- radius of hammer path
- center of mass of the system
- center of mass of the thrower
- shoulder to hip angle
- athlete mass
- hammer mass

Model

The general model will be

$$\mu\{distthrown\} = \beta_0 + \beta_1 gender + \beta_2 IV + \beta_3 (IV * gender))$$

for the above 9 independent variables (IV).

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Appendix A-1
Figures

LEGEND OF FIGURES

Figure 1: Long-handled hammer – Scottish Games

Figure 2: Complete hammer

Figure 3: Hammer Throw ring and sector dimensions

Figure 4: Hammer Throw Grip

Figure 5: Hammer Throw Sequence - Winds

Figure 6: Hammer Throw Sequence - Transition

Figure 7: Hammer Throw Sequence – Turns

Figure 8: Hammer Throw Sequence - Turns – Footwork

Figure 9: Hammer Throw Sequence – Release

Figure 10: Hammer Throw Sequence – Final pull during release

Figure 11: Complete Hammer Throw Sequence

Figure 12: Video Camera Setup – 2003 USA National Championships, Palo Alto, CA

Figure 13: Video Camera Setup – 2003 IAAF World Athletic Final, Szombathely, Hungary

Figure 14: Calculation of the radius of the hammer path

Figure 15: Digitizing model

Fig. 1: Long handled hammer – Scottish Games

Fig. 2: Hammer

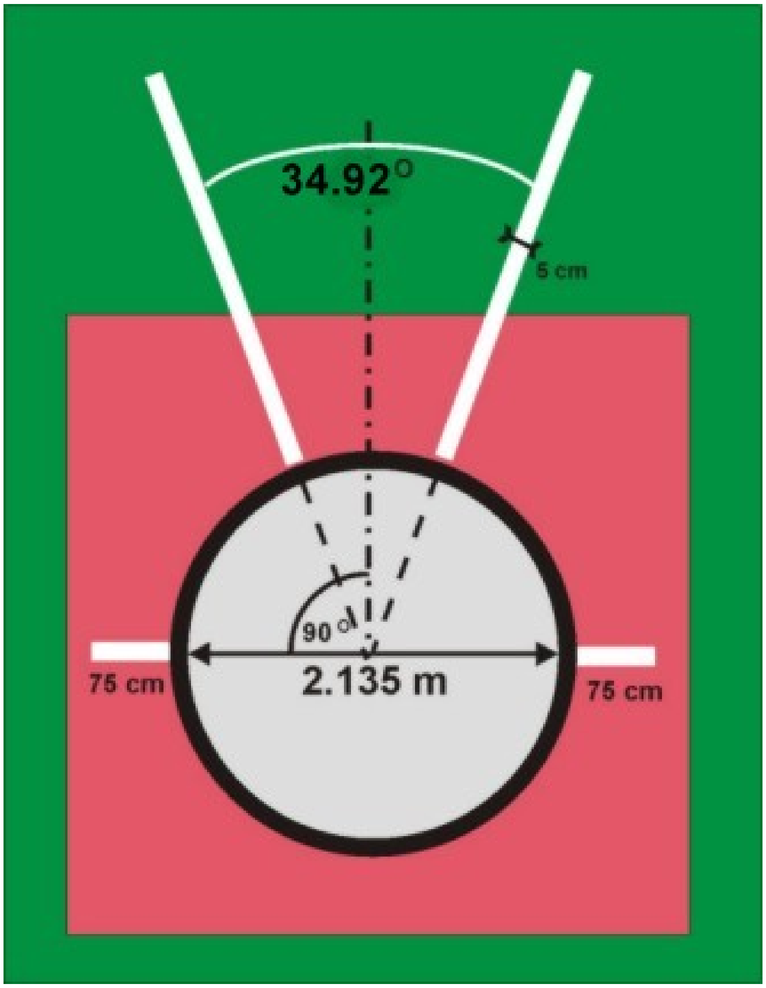

Fig. 3: Hammer Throw ring dimensions

Fig. 4: Hammer Throw Grip

Fig. 5: Hammer Throw Sequence - Winds

Fig. 6: Hammer Throw Sequence – Transition -Entry into Turn 1

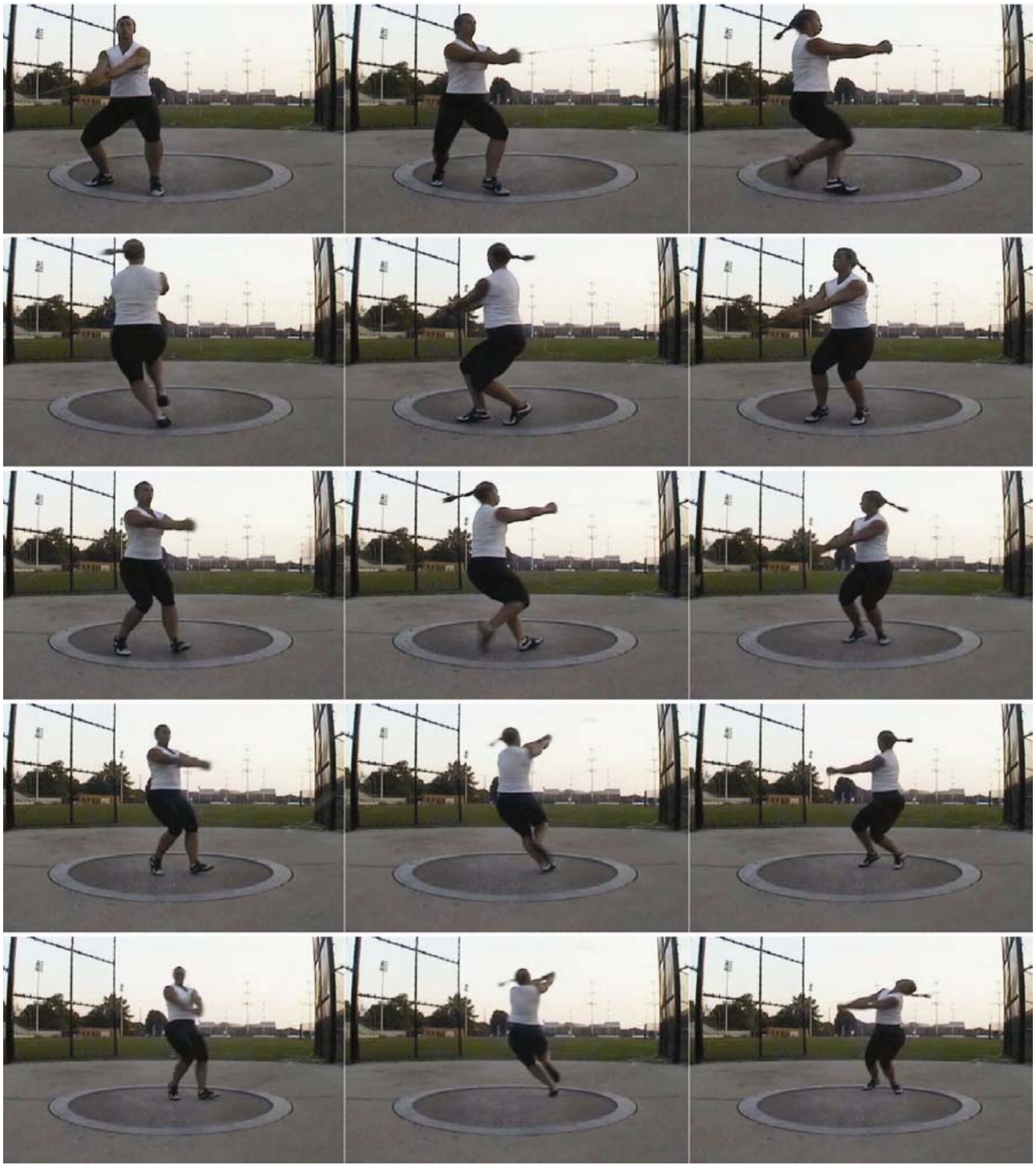

Fig. 7: Hammer Throw Sequence – Turns

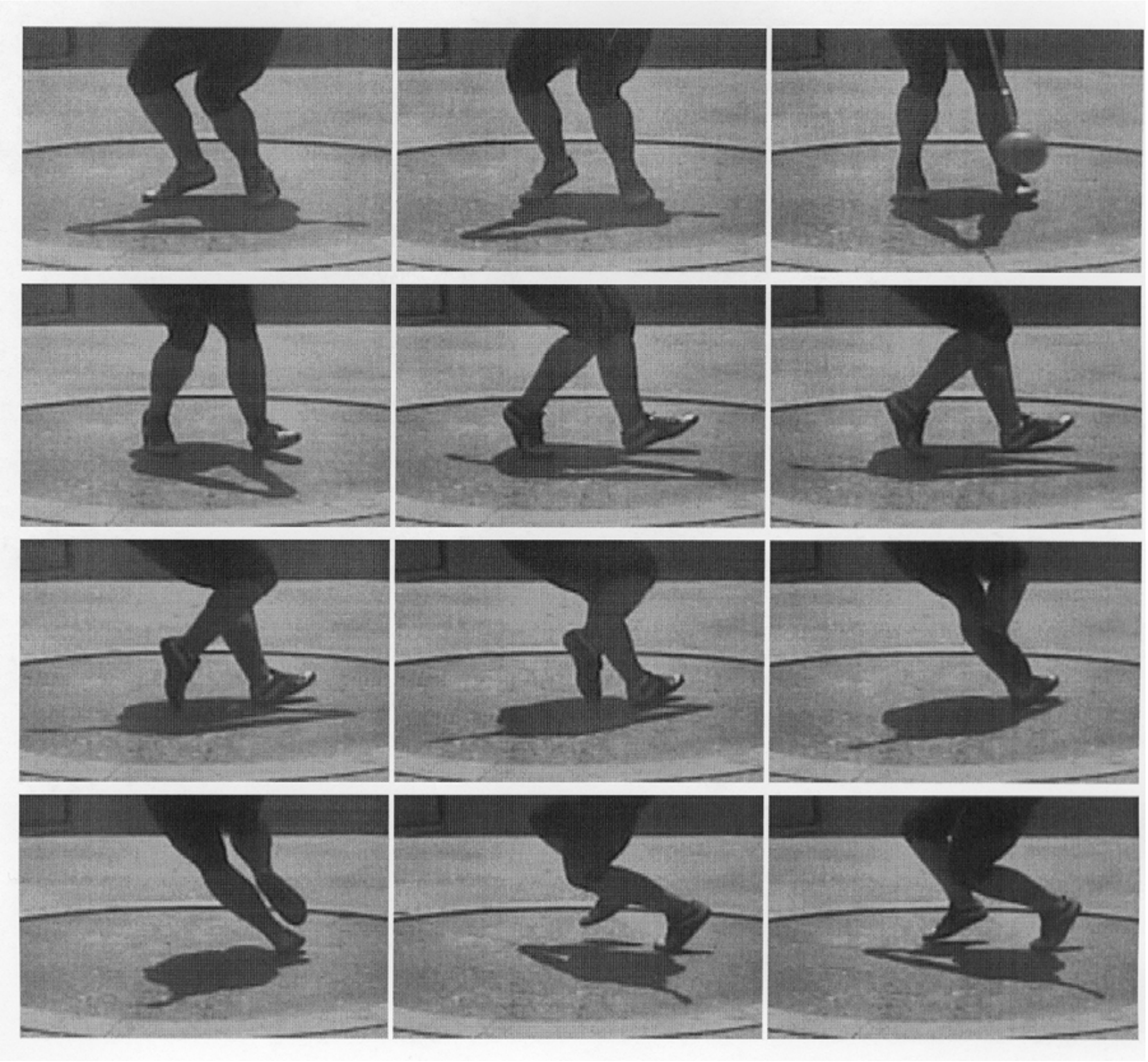

Fig. 8: Hammer Throw Sequence – Turns - Foot Work

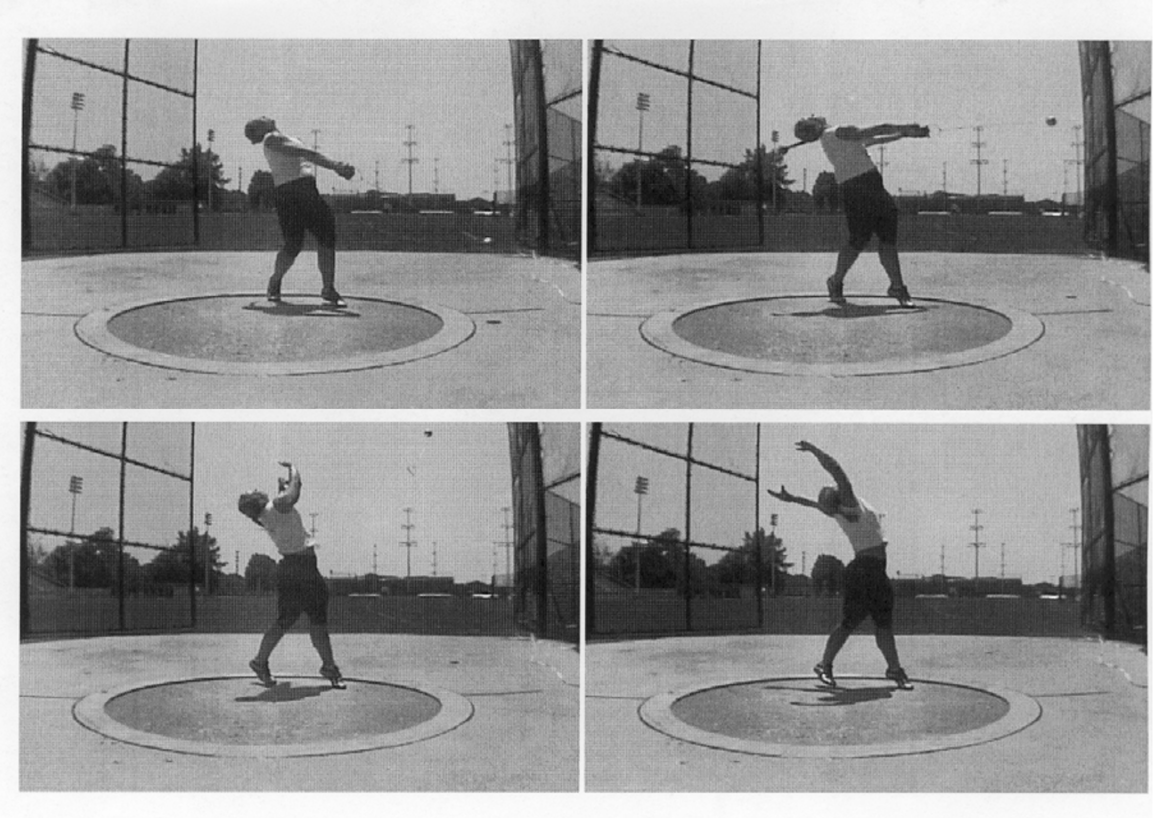

Fig. 9: Hammer Throw Sequence – Release

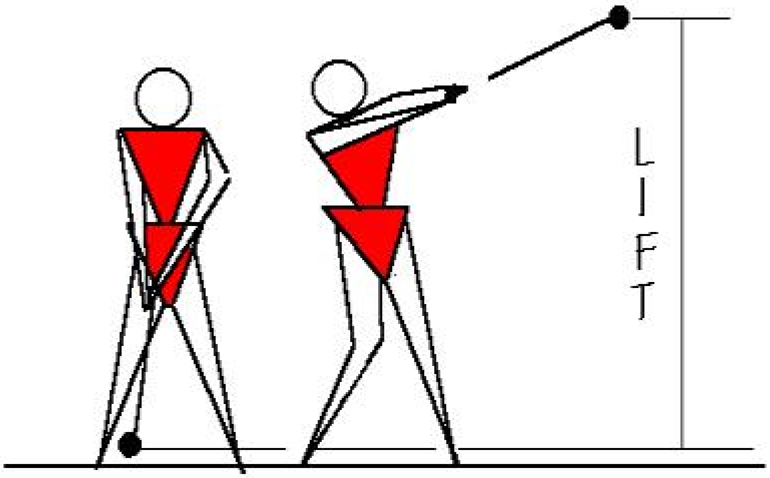

Fig. 10: Final Effort at Release of Hammer

Fig. 11: Complete Hammer Throw Sequence

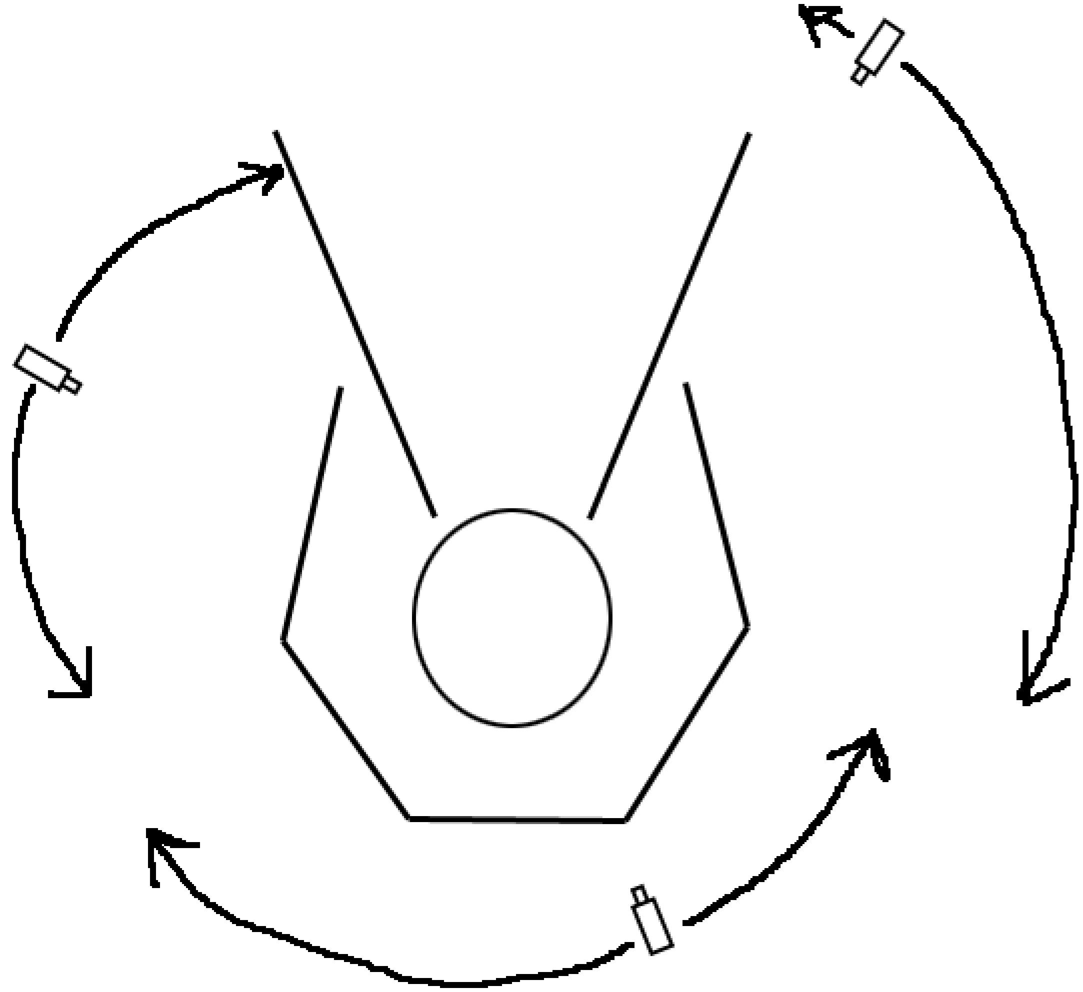

Fig. 12: Video Camera Setup – 2003 USA National Championships, Palo Alto, CA

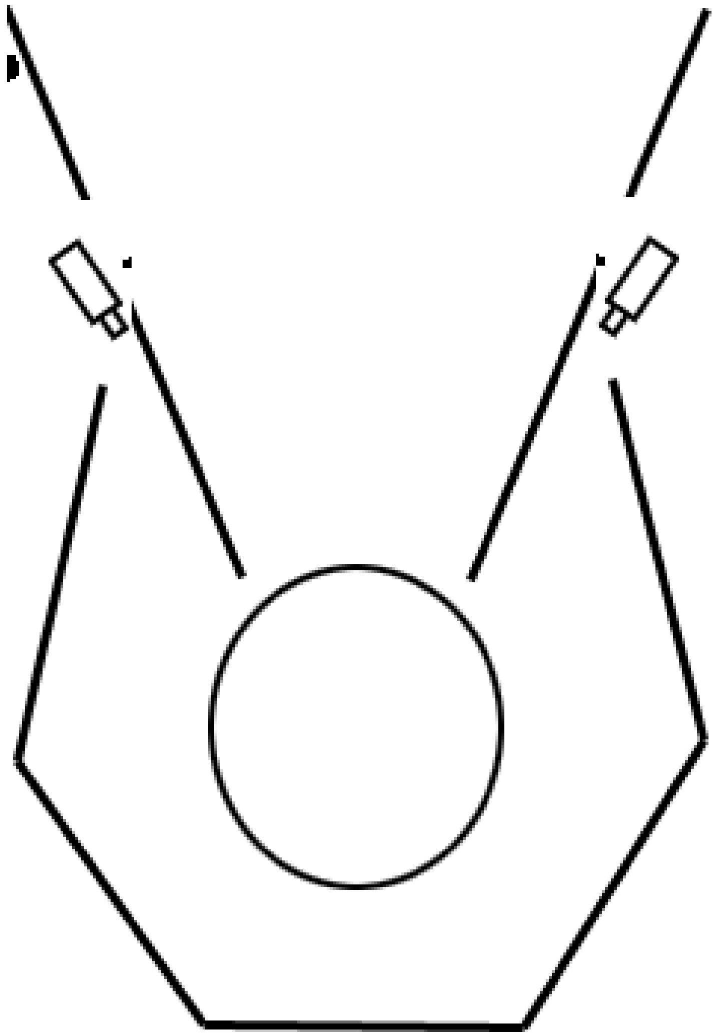

Fig. 13: Video Camera Setup – 2003 IAAF World Athletic Final, Szombathely, Hungary

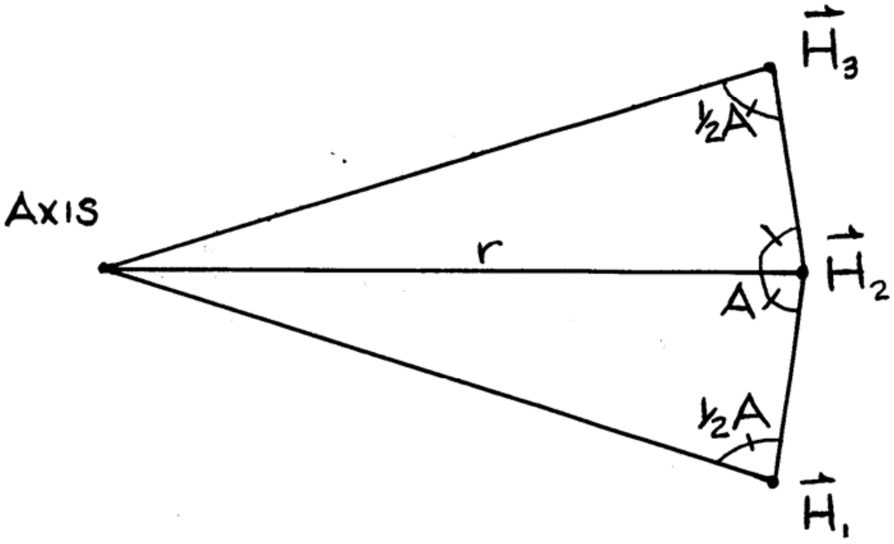

Fig. 14: Calculation of the radius of the hammer path

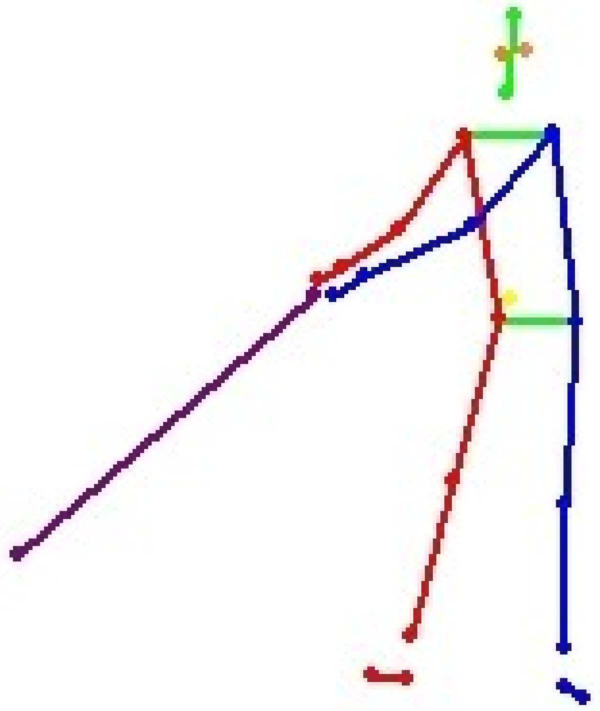

Fig. 15: Digitizing model

Appendix B: Additional Tables

Table 5. Means and standard deviations between sexes

Variable	Men (n=14)		Female (n=15)	
	Mean	SD	Mean	SD
Mass (kg)	112.857	13.002	86.733	12.898
Height (m)	1.889	0.059	1.758	0.067
Total Time (s)	2.218	0.183	2.073	0.225
Release Angle (deg)	41.367	6.606	41.770	3.151
Release Vel (m/s)	29.150	1.384	27.524	1.154
Release Height (m)	1.137	0.407	1.412	0.329
Chg Throw Z (m)	0.066	0.041	0.086	0.056
Thr COM travel	1.588	0.121	1.368	0.204
Thr COM ang	12.819	10.294	8.486	8.142
Chg System Z (m)	0.008	0.008	0.011	0.006
Sys COM travel(m)	0.084	0.015	0.092	0.012
Sys COM ang (deg)	28.986	14.183	23.030	11.447
Height Swing Foot (m)				
Turn 1	0.025	0.031	0.017	0.016
Turn 2	0.016	0.026	0.022	0.025
Turn 3	0.016	0.033	0.027	0.027
Turn 4	0.020	0.037	0.033	0.028
Height of Swing Hip (m)				
Turn 1	0.768	0.055	0.710	0.075
Turn 2	0.749	0.059	0.723	0.079
Turn 3	0.768	0.047	0.742	0.069
Turn 4	0.794	0.045	0.776	0.051
Low Point Y of hammer head (m)				
Turn 1	-0.619	0.261	-0.454	0.317
Turn 2	-0.199	0.307	0.060	0.327
Turn 3	0.333	0.235	0.542	0.258
Turn 4	0.739	0.480	0.707	0.451
High Point Y of hammer head (m)				
Turn 1	2.495	0.261	2.506	0.243
Turn 2	2.685	0.259	2.683	0.264
Turn 3	2.936	0.212	2.945	0.260
Turn 4	3.261	0.247	3.247	0.216
Low Point Z of hammer head (m)				
Turn 1	0.311	0.108	0.261	0.137
Turn 2	0.216	0.101	0.165	0.072

Variable	Men (n=14)		Female (n=15)	
	Mean	SD	Mean	SD
Turn 3	0.174	0.156	0.113	0.044
Turn 4	0.099	0.071	0.067	0.044
High Point Z of hammer head (m)				
Turn 1	1.701	0.164	1.725	0.163
Turn 2	1.942	0.153	1.999	0.159
Turn 3	2.128	0.173	2.173	0.167
Turn 4	2.258	0.173	2.272	0.127
Turn Ratio – ratio of single stance to double stance				
Turn 1	0.885	0.124	1.114	0.458
Turn 2	1.033	0.097	1.241	0.358
Turn 3	1.201	0.230	1.440	0.531
Turn 4	1.042	0.270	1.206	0.381
Orbit (deg)				
Turn 1	35.114	8.612	36.022	17.537
Turn 2	35.098	5.763	37.238	5.858
Turn 3	40.990	6.554	42.363	6.163
Turn 4	39.645	6.419	41.353	6.010
Average Length of Radius (m)				
Turn 1	1.735	0.095	1.689	0.199
Turn 2	1.704	0.071	1.655	0.163
Turn 3	1.659	0.069	1.639	0.111
Turn 4	1.660	0.089	1.588	0.148
Minimum Length of Radius (m)				
Turn 1	1.317	0.255	1.228	0.362
Turn 2	1.395	0.174	1.253	0.338
Turn 3	1.371	0.147	1.325	0.163
Turn 4	1.379	0.148	1.229	0.266
Maximum Length of Radius (m)				
Turn 1	2.350	0.369	2.250	0.502
Turn 2	2.172	0.251	2.181	0.508
Turn 3	2.073	0.169	2.079	0.383
Turn 4	2.234	0.174	2.229	0.221
Change in Length of Radius (m)				
Turn 1	1.033	0.592	1.022	0.782
Turn 2	0.777	0.366	0.928	0.771
Turn 3	0.669	0.210	0.677	0.474

Variable	Men (n=14)		Female (n=15)	
	Mean	SD	Mean	SD
Turn 4	0.545	0.221	0.685	0.405
Average Location of Minimum Radius (deg)				
Turn 1	240.64	102.60	241.46	72.13
Turn 2	288.66	57.82	272.49	69.07
Turn 3	260.96	95.71	288.23	43.19
Turn 4	301.72	91.57	271.54	99.71
Average Location of Maximum Radius (deg)				
Turn 1	100.37	83.31	110.06	110.53
Turn 2	158.84	100.08	143.89	118.39
Turn 3	88.55	95.63	110.01	68.46
Turn 4	128.24	110.75	71.56	52.94
Turn Time (s)				
Turn 1	0.719	0.104	0.638	0.077
Turn 2	0.532	0.053	0.540	0.059
Turn 3	0.473	0.029	0.460	0.036
Turn 4	0.465	0.076	0.429	0.037
Minimum Ratio – ratio of when minimum radius occurs based upon time				
Turn 1	0.643	0.218	0.558	0.187
Turn 2	0.634	0.228	0.629	0.144
Turn 3	0.631	0.189	0.616	0.171
Turn 4	0.744	0.147	0.620	0.253
Maximum Ratio				
Turn 1	0.383	0.352	0.664	0.292
Turn 2	0.241	0.333	0.641	0.354
Turn 3	0.285	0.364	0.451	0.349
Turn 4	0.085	0.088	0.126	0.154
Angle between the Shoulders and the Hammer Head (deg)				
SS 1	97.396	12.663	97.813	7.093
DS 1	104.196	15.799	110.234	12.560
SS 2	96.455	11.840	97.715	13.892
DS 2	103.593	16.178	103.738	10.189
SS 3	98.326	16.448	93.315	9.839
DS 3	104.016	15.965	104.915	13.125
SS 4	98.607	10.877	91.823	11.734
DS 4	98.0493	16.453	106.316	19.005

Variable	Men (n=14)		Female (n=15)	
	Mean	SD	Mean	SD
Angle between the Shoulders and the Hips (deg)				
SS 1	9.949	5.732	7.871	6.722
DS 1	29.874	15.722	14.566	8.994
SS 2	12.467	7.407	15.791	12.179
DS 2	29.598	13.890	28.383	12.043
SS 3	15.710	7.806	18.663	11.851
DS 3	26.409	14.931	22.485	14.516
SS 4	32.377	33.926	14.368	10.470
DS 4	125.717	54.963	122.941	40.062
Phase time – time for each phase with a turn(s)				
SS 1	0.333	0.031	0.326	0.038
DS 1	0.386	0.079	0.314	0.073
SS 2	0.269	0.028	0.296	0.065
DS 2	0.262	0.030	0.247	0.032
SS 3	0.256	0.030	0.268	0.028
DS 3	0.217	0.024	0.189	0.066
SS 4	0.248	0.033	0.263	0.044
DS 4	0.248	0.051	0.260	0.212
Radius of the Hammer Path (m)				
SS 1	1.887	0.334	1.749	0.337
DS 1	1.584	0.237	1.504	0.597
SS 2	1.885	0.349	1.839	0.513
DS 2	1.566	0.254	1.470	0.390
SS 3	1.897	0.318	1.828	0.411
DS 3	1.626	0.194	1.586	0.342
SS 4	1.913	0.315	1.814	0.242
DS 4	1.870	0.813	1.579	0.244
Centripal Force (N)				
SS 1	11171.287	5807.954	6130.269	1513.549
DS 1	12171.262	6037.833	9677.900	1758.988
SS 2	17952.547	8095.382	9127.474	2193.692
DS 2	19062.655	8513.591	10555.696	3140.849
SS 3	23311.889	8582.243	11655.629	2816.595
DS 3	23148.097	9381.759	12058.993	1650.775
SS 4	26678.995	8795.814	13172.467	1700.745
DS 4	24522.264	9362.181	13762.180	2886.769

Table 6. Means and standard deviation for variables of interest for performance

Variable	N	Mean	Std. Dev
Mass (kg)	29	99.345	18.389
Height (m)	29	1.821	0.091
Distance (m)	29	71.396	5.721
Total Time (s)	29	2.140	0.21
Release Angle (deg)	29	41.575	5.026
Release Velocity (m/s)	29	28.309	1.497
Release Height (m)	29	1.28	0.388
Change of Thrower X (m)	29	0.263	0.229
Change of Thrower Y (m)	29	1.418	0.196
Change of Thrower Z (m)	29	0.076	0.049
Thrower COM travel (m)	29	1.460	0.192
Thrower COM angle (deg)	29	10.578	9.338
Change of System X (m)	29	0.036	0.014
Change of System Y (m)	29	0.078	0.019
Change of System Z(m)	29	0.009	0.007
System COM travel (m)	29	0.088	0.014
System COM angle (deg)	29	25.905	12.965
Height of Swing Foot (m)			
Turn 1	29	0.020	0.025
Turn 2	29	0.019	0.025
Turn 3	29	0.022	0.030
Turn 4	27	0.026	0.033
Height of Swing Hip (m)			
Turn 1	29	0.738	0.077
Turn 2	29	0.735	0.070
Turn 3	29	0.754	0.061
Turn 4	27	0.777	0.050
Low Point Y of hammer head (m)			
Turn 1	29	-0.533	0.298
Turn 2	29	-0.065	0.338
Turn 3	29	0.441	0.265
Turn 4	27	0.723	0.458
High Point Y of hammer head (m)			
Turn 1	29	2.500	0.247
Turn 2	29	2.683	0.256

Variable	N	Mean	Std. Dev
Turn 3	29	2.940	0.234
Turn 4	27	3.254	0.228
Low Point Z of hammer head (m)			
Turn 1	29	0.285	0.124
Turn 2	29	0.189	0.089
Turn 3	29	0.142	0.115
Turn 4	27	0.084	0.061
High Point Z of hammer head (m)			
Turn 1	29	1.713	0.161
Turn 2	29	1.971	0.156
Turn 3	29	2.151	0.169
Turn 4	27	2.265	0.15
Orbit (deg)			
Turn 1	29	35.84	13.726
Turn 2	29	36.205	5.282
Turn 3	28	41.676	6.282
Turn 4	27	40.467	6.167
Average Radius (m)			
Turn 1	29	1.711	0.156
Turn 2	29	1.678	0.127
Turn 3	29	1.649	0.092
Turn 4	27	1.625	0.124
Minimum Radius (m)			
Turn 1	29	1.271	0.312
Turn 2	29	1.322	0.277
Turn 3	29	1.347	0.154
Turn 4	27	1.307	0.222
Maximum Radius (m)			
Turn 1	29	2.298	0.438
Turn 2	29	2.177	0.398
Turn 3	29	2.076	0.294
Turn 4	27	2.231	0.194
Change in Radius (m)			
Turn 1	29	1.027	0.684
Turn 2	29	0.855	0.605
Turn 3	29	0.673	0.364
Turn 4	27	0.613	0.324

Variable	N	Mean	Std. Dev
Average Location of Minimum Radius (deg)			
Turn 1	29	241.067	86.538
Turn 2	29	280.297	63.286
Turn 3	29	275.07	73.33
Turn 4	27	287.19	94.96
Average Location of Maximum Radius (deg)			
Turn 1	29	105.38	96.72
Turn 2	29	151.11	108.24
Turn 3	29	99.64	80.29
Turn 4	27	100.95	90.88
Radius from shoulders to hammer head (m)			
SS 1	29	1.816	0.337
DS 1	29	1.542	0.453
SS 2	29	1.871	0.428
DS 2	29	1.517	0.329
SS 3	29	1.86	0.329
DS 3	29	1.61	0.277
SS 4	27	1.865	0.281
DS 4	27	1.73	0.616
Turn Time - Time duration for each turn (s)			
Turn 1	29	0.677	0.098
Turn 2	29	0.536	0.056
Turn 3	29	0.466	0.032
Turn 4	27	0.435	0.041
Phasetime – Time the athlete spends in each phase of each turn – (s)			
SS 1	29	0.329	0.034
DS 1	29	0.349	0.083
SS 2	29	0.283	0.051
DS 2	29	0.254	0.031
SS 3	29	0.262	0.030
DS 3	29	0.202	0.051
SS 4	27	0.255	0.039
DS 4	27	0.241	0.050
Angle between Shoulder and Hammer Head (deg)			
SS 1	29	97.611	9.982
DS 1	29	107.956	14.29
DS 2	29	97.107	12.727
SS 2	29	103.668	13.168

Variable	N	Mean	Std. Dev
SS 3	29	95.734	13.435
DS 3	29	104.481	14.307
SS 4	27	95.341	11.603
DS 4	27	102.26	17.83
Angle between the shoulder and hips (deg)			
SS 1	29	8.874	6.242
DS 1	29	21.956	14.691
SS 2	29	14.187	10.124
DS 2	29	28.97	12.747
SS 3	29	17.238	10.038
DS 3	29	24.38	14.589
SS 4	27	23.706	26.65
DS 4	27	124.38	47.47
Centripal_Force (N)			
SS 1	29	8563.86	4835.17
DS 1	29	10881.59	9363.25
SS 2	29	13387.85	7278.40
DS 2	29	14662.5	7569.7
SS 3	29	17282.79	8561.65
DS 3	29	17412.35	8604.06
SS 4	27	20175.85	9344.19
DS 4	27	15912.41	3142.33

Appendix C: Subject Data

Table 7. Subject Data for Single Event Variables

Athlete	Sub	Sex	Country	Mass	Hgt	Distance	TotalTime	RelAng	RelVel	RelHgt
Annus	1	0	1	102.00	1.94	82.10	2.13	34.49	29.86	0.82
Keil	2	1	1	70.00	1.75	67.78	1.92	42.01	28.97	1.39
Kobs	3	0	1	118.00	1.96	74.18	2.50	44.89	28.01	1.37
Konovalov	4	0	1	106.00	1.92	78.57	2.42	40.51	29.33	1.21
Kozmus	5	0	1	106.00	1.88	78.59	2.10	37.23	30.99	1.70
Kuzenkova	6	1	1	76.00	1.76	71.16	2.18	45.10	28.38	1.45
Charfreitag	7	0	1	117.00	1.91	81.22	2.25	42.38	29.44	1.70
Mahon WAC	8	1	1	82.00	1.81	66.94	2.20	39.12	27.95	1.60
Melinte	9	1	1	84.00	1.70	69.27	2.10	44.60	28.10	1.59
Montebrun	10	1	1	92.00	1.75	68.88	2.10	42.19	28.24	1.71
Moreno	11	1	1	71.00	1.68	73.42	2.22	35.60	29.13	2.10
Murofushi	12	0	1	96.00	1.87	79.12	1.98	38.10	29.50	1.29
Sekochova	13	1	1	66.00	1.64	66.46	1.97	39.90	27.45	1.07
Skolimowska	14	1	1	105.00	1.81	61.46	1.68	47.57	25.80	1.75
Skvaruk	15	0	1	103.00	1.86	78.76	2.38	44.49	27.37	1.23
Tikhon	16	0	1	110.00	1.86	80.84	1.93	38.03	31.03	0.89
Ellerbe	17	1	0	109.00	1.88	66.76	1.57	43.23	25.70	1.01
Campbell	18	1	0	91.00	1.70	65.58	2.18	37.76	27.43	1.05
Dickerson	19	1	0	100.00	1.75	65.58	2.05	38.90	27.80	1.01
Freeman	20	0	0	146.00	1.96	70.08	2.32	56.81	29.45	0.49
Gilreath	21	1	0	91.00	1.78	64.22	2.33	40.38	26.09	1.54
MacKay	22	0	0	132.00	1.96	68.59	2.48	31.16	30.19	1.07
Mahon	23	1	0	82.00	1.81	69.04	2.13	44.25	26.60	1.22
McEwen	24	0	0	116.00	1.91	72.96	2.23	44.16	28.86	1.09

Athlete	Sub	Sex	Country	Mass	Hgt	Distance	TotalTime	RelAng	RelVel	RelHgt
McGrath	25	0	0	105.00	1.81	71.98	2.03	790.69	30.08	0.30
Moton	26	1	0	98.00	1.85	64.02	2.43	43.16	26.40	1.61
Nutter	27	0	0	109.00	1.78	69.54	2.10	50.00	27.84	1.49
Parker	28	0	0	114.00	1.82	73.04	2.18	41.20	26.16	1.28
Price	29	1	0	84.00	1.70	70.34	2.03	42.78	28.82	1.08

Table 7. Subject Data for Single Event Variables (cont.)

Athlete	**Sub**	**Sex**	**Country**	**Change_X_T**	**Change_Y_T**	**Change_Z_T**	**COM_T_travel**	**Angle_COM_T**
Annus	1	0	1	0.34	1.59	0.07	1.63	12.02
Keil	2	1	1	0.00	1.21	0.06	1.21	0.23
Kobs	3	0	1	0.02	1.26	0.07	1.26	0.84
Konovalov	4	0	1	0.02	1.50	0.06	1.50	0.68
Kozmus	5	0	1	0.12	1.64	0.08	1.64	4.30
Kuzenkova	6	1	1	0.02	1.39	0.01	1.39	0.97
Charfreitag	7	0	1	0.16	1.62	0.10	1.63	5.78
Mahon WAC	8	1	1	0.29	1.39	0.03	1.42	11.93
Melinte	9	1	1	0.29	1.24	0.18	1.27	13.04
Montebrun	10	1	1	0.03	1.31	0.02	1.31	1.25
Moreno	11	1	1	0.07	1.48	0.16	1.49	2.66
Murofushi	12	0	1	0.21	1.54	0.09	1.55	7.82
Sekochova	13	1	1	0.07	1.45	0.15	1.46	2.81
Skolimowska	14	1	1	0.35	0.66	0.14	0.75	27.80
Skvaruk	15	0	1	0.07	1.53	0.07	1.53	2.73
Tikhon	16	0	1	0.43	1.67	0.01	1.73	14.48
Ellerbe	17	1	0	0.43	1.26	0.06	1.33	18.86
Campbell	18	1	0	0.18	1.51	0.09	1.52	6.82
Dickerson	19	1	0	0.30	1.42	0.04	1.45	12.06
Freeman	20	0	0	0.84	1.46	0.03	1.69	29.84
Gilreath	21	1	0	0.16	1.55	0.08	1.56	5.87
MacKay	22	0	0	0.30	1.49	0.18	1.52	11.46
Mahon	23	1	0	0.04	1.29	0.04	1.29	1.56
McEwen	24	0	0	0.52	1.49	0.05	1.58	19.28

Athlete	Sub	Sex	Country	Change_X_T	Change_Y_T	Change_Z_T	COM_T_travel	Angle_COM_T
McGrath	25	0	0	0.83	1.24	0.04	1.50	33.66
Moton	26	1	0	0.10	1.51	0.14	1.52	3.95
Nutter	27	0	0	0.49	1.32	0.05	1.41	20.19
Parker	28	0	0	0.46	1.58	0.02	1.65	16.37
Price	29	1	0	0.47	1.50	0.08	1.57	17.47

Table 7. Subject Data for Single Event Variables(cont.)

Athlete	Sub	Sex	Country	Change_X_S	Change_Y_S	Change_Z_S	COM_S_travel	Angle_COM_S
Annus	1	0	1	0.05	0.07	0.00	0.08	35.35
Keil	2	1	1	0.01	0.09	0.01	0.09	9.34
Kobs	3	0	1	0.02	0.05	0.00	0.06	21.14
Konovalov	4	0	1	0.03	0.08	0.00	0.08	20.32
Kozmus	5	0	1	0.01	0.11	0.01	0.11	4.97
Kuzenkova	6	1	1	0.03	0.08	0.01	0.09	20.38
Charfreitag	7	0	1	0.02	0.10	0.02	0.11	12.11
Mahon WAC	8	1	1	0.02	0.08	0.00	0.09	10.18
Melinte	9	1	1	0.05	0.08	0.02	0.09	29.84
Montebrun	10	1	1	0.03	0.09	0.00	0.10	17.18
Moreno	11	1	1	0.03	0.10	0.02	0.10	19.44
Murofushi	12	0	1	0.02	0.08	0.00	0.09	14.88
Sekochova	13	1	1	0.02	0.11	0.01	0.11	7.77
Skolimowska	14	1	1	0.06	0.04	0.01	0.08	53.54
Skvaruk	15	0	1	0.02	0.08	0.00	0.08	17.65
Tikhon	16	0	1	0.05	0.09	0.00	0.10	29.03
Ellerbe	17	1	0	0.05	0.07	0.02	0.08	33.38
Campbell	18	1	0	0.04	0.09	0.01	0.10	22.00
Dickerson	19	1	0	0.05	0.09	0.01	0.10	28.13
Freeman	20	0	0	0.06	0.07	0.00	0.09	41.28
Gilreath	21	1	0	0.04	0.09	0.01	0.10	21.85
MacKay	22	0	0	0.05	0.06	0.01	0.08	42.38
Mahon	23	1	0	0.03	0.05	0.01	0.06	30.25
McEwen	24	0	0	0.05	0.06	0.01	0.08	42.54

Athlete	Sub	Sex	Country	Change_X_S	Change_Y_S	Change_Z_S	COM_S_travel	Angle_COM_S
McGrath	25	0	0	0.05	0.03	0.00	0.06	54.73
Moton	26	1	0	0.03	0.09	0.02	0.10	17.72
Nutter	27	0	0	0.04	0.07	0.02	0.08	32.89
Parker	28	0	0	0.05	0.06	0.02	0.08	36.52
Price	29	1	0	0.04	0.09	0.01	0.09	24.46

Table 8. Subject Data for Turn Event Variables

Athlete	Sub_Num	Sex	Country	Turn	Mass	Hgt	Time	Distance	HgtofFt	HgtHip
Annus	1	0	1	1	102	1.94	1.58	82.10	0.04	0.78
Annus	1	0	1	2	102	1.94	2.28	82.10	0.02	0.75
Annus	1	0	1	3	102	1.94	2.80	82.10	-0.01	0.80
Annus	1	0	1	4	102	1.94	3.27	82.10	0.00	0.84
Keil	2	1	1	1	70	1.75	1.13	67.78	0.04	0.68
Keil	2	1	1	2	70	1.75	1.65	67.78	0.05	0.68
Keil	2	1	1	3	70	1.75	2.12	67.78	0.06	0.69
Keil	2	1	1	4	70	1.75	2.57	67.78	0.07	0.76
Kobs	3	0	1	1	118	1.96	1.88	74.18	0.05	0.88
Kobs	3	0	1	2	118	1.96	2.77	74.18	0.02	0.84
Kobs	3	0	1	3	118	1.96	3.40	74.18	-0.01	0.84
Kobs	3	0	1	4	118	1.96	3.92	74.18	0.00	0.86
Konovalov	4	0	1	1	106	1.92	2.15	78.57	0.02	0.74
Konovalov	4	0	1	2	106	1.92	3.03	78.57	0.00	0.66
Konovalov	4	0	1	3	106	1.92	3.62	78.57	-0.03	0.70
Konovalov	4	0	1	4	106	1.92	4.10	78.57	-0.02	0.74
Kozmus	5	0	1	1	106	1.88	0.87	78.59	0.02	0.78
Kozmus	5	0	1	2	106	1.88	1.53	78.59	0.03	0.76
Kozmus	5	0	1	3	106	1.88	2.05	78.59	0.01	0.80
Kozmus	5	0	1	4	106	1.88	2.50	78.59	0.01	0.81
Kuzenkova	6	1	1	1	76	1.76	1.38	71.16	0.00	0.82
Kuzenkova	6	1	1	2	76	1.76	2.07	71.16	-0.02	0.78
Kuzenkova	6	1	1	3	76	1.76	2.60	71.16	-0.03	0.77

Athlete	Sub_Num	Sex	Country	Turn	Mass	Hgt	Time	Distance	HgtofFt	HgtHip
Kuzenkova	6	1	1	4	76	1.76	3.07	71.16	-0.03	0.78
Charfreitag	7	0	1	1	117	1.91	1.35	81.22	0.04	0.85
Charfreitag	7	0	1	2	117	1.91	2.05	81.22	0.03	0.78
Charfreitag	7	0	1	3	117	1.91	2.62	81.22	0.01	0.78
Charfreitag	7	0	1	4	117	1.91	3.12	81.22	0.01	0.83
Mahon WAC	8	1	1	1	82	1.81	1.08	66.94	0.03	0.73
Mahon WAC	8	1	1	2	82	1.81	1.78	66.94	0.04	0.73
Mahon WAC	8	1	1	3	82	1.81	2.30	66.94	0.03	0.75
Mahon WAC	8	1	1	4	82	1.81	2.77	66.94	0.04	0.79
Melinte	9	1	1	1	84	1.70	1.17	69.27	0.03	0.64
Melinte	9	1	1	2	84	1.70	1.78	69.27	0.04	0.66
Melinte	9	1	1	3	84	1.70	2.28	69.27	0.06	0.69
Melinte	9	1	1	4	84	1.70	2.70	69.27	0.05	0.76
Montebrun	10	1	1	1	92	1.75	1.40	68.88	0.03	0.71
Montebrun	10	1	1	2	92	1.75	2.05	68.88	0.05	0.68
Montebrun	10	1	1	3	92	1.75	2.55	68.88	0.06	0.72
Montebrun	10	1	1	4	92	1.75	3.02	68.88	0.05	0.75
Moreno	11	1	1	1	71	1.68	1.43	73.42	0.01	0.52
Moreno	11	1	1	2	71	1.68	1.97	73.42	0.01	0.54
Moreno	11	1	1	3	71	1.68	2.65	73.42	0.03	0.59
Moreno	11	1	1	4	71	1.68	3.08	73.42	0.04	0.62
Murofushi	12	0	1	1	96	1.87	0.98	79.12	0.01	0.72
Murofushi	12	0	1	2	96	1.87	1.60	79.12	0.00	0.70
Murofushi	12	0	1	3	96	1.87	2.07	79.12	0.03	0.77
Murofushi	12	0	1	4	96	1.87	2.50	79.12	0.02	0.81

Athlete	Sub_Num	Sex	Country	Turn	Mass	Hgt	Time	Distance	HgtofFt	HgtHip
Sekochova	13	1	1	1	66	1.64	1.23	66.46	0.04	0.57
Sekochova	13	1	1	2	66	1.64	1.82	66.46	0.04	0.61
Sekochova	13	1	1	3	66	1.64	2.33	66.46	0.06	0.62
Sekochova	13	1	1	4	66	1.64	2.75	66.46	0.06	0.72
Skolimowska	14	1	1	1	105	1.81	1.25	61.46	0.01	0.72
Skolimowska	14	1	1	2	105	1.81	1.90	61.46	0.03	0.73
Skolimowska	14	1	1	3	105	1.81	2.43	61.46	0.01	0.78
Skvaruk	15	0	1	1	103	1.86	1.98	78.76	0.02	0.73
Skvaruk	15	0	1	2	103	1.86	2.85	78.76	0.00	0.66
Skvaruk	15	0	1	3	103	1.86	3.42	78.76	0.01	0.70
Skvaruk	15	0	1	4	103	1.86	3.88	78.76	0.00	0.74
Tikhon	16	0	1	1	110	1.86	1.22	80.84	-0.01	0.75
Tikhon	16	0	1	2	110	1.86	1.80	80.84	0.02	0.74
Tikhon	16	0	1	3	110	1.86	2.27	80.84	0.03	0.73
Tikhon	16	0	1	4	110	1.86	2.70	80.84	0.05	0.77
Ellerbe	17	1	0	1	109	1.88	0.32	66.76	0.01	0.82
Ellerbe	17	1	0	2	109	1.88	0.92	66.76	0.00	0.86
Ellerbe	17	1	0	3	109	1.88	1.43	66.76	0.00	0.85
Campbell	18	1	0	1	91	1.70	1.08	64.02	0.01	0.70
Campbell	18	1	0	2	91	1.70	1.68	64.02	0.04	0.74
Campbell	18	1	0	3	91	1.70	2.25	64.02	0.03	0.78
Campbell	18	1	0	4	91	1.70	2.77	64.02	0.06	0.79
Dickerson	19	1	0	1	100	1.75	1.40	65.58	0.01	0.76
Dickerson	19	1	0	2	100	1.75	1.97	65.58	0.04	0.76
Dickerson	19	1	0	3	100	1.75	2.48	65.58	0.03	0.77

Athlete	Sub_Num	Sex	Country	Turn	Mass	Hgt	Time	Distance	HgtofFt	HgtHip
Dickerson	19	1	0	4	100	1.75	2.95	65.58	0.02	0.77
Freeman	20	0	0	1	146	1.96	1.22	70.08	0.01	0.86
Freeman	20	0	0	2	146	1.96	1.95	70.08	0.00	0.86
Freeman	20	0	0	3	146	1.96	2.55	70.08	0.01	0.87
Freeman	20	0	0	4	146	1.96	3.00	70.08	0.02	0.86
Gilreath	21	1	0	1	91	1.78	1.57	64.83	0.02	0.74
Gilreath	21	1	0	2	91	1.78	2.32	64.83	0.02	0.76
Gilreath	21	1	0	3	91	1.78	2.90	64.83	0.01	0.78
Gilreath	21	1	0	4	91	1.78	3.43	64.83	0.02	0.78
MacKay	22	0	0	1	132	1.96	1.35	68.59	0.00	0.74
MacKay	22	0	0	2	132	1.96	2.18	68.59	-0.01	0.78
MacKay	22	0	0	3	132	1.96	2.67	68.59	-0.01	0.79
MacKay	22	0	0	4	132	1.96	3.20	68.59	-0.01	0.79
Mahon	23	1	0	1	82	1.81	1.48	69.04	-0.01	0.76
Mahon	23	1	0	2	82	1.81	2.15	69.04	-0.02	0.76
Mahon	23	1	0	3	82	1.81	2.68	69.04	0.00	0.76
Mahon	23	1	0	4	82	1.81	3.15	69.04	0.01	0.81
McEwen	24	0	0	1	116	1.91	1.35	72.96	0.01	0.76
McEwen	24	0	0	2	116	1.91	2.05	72.96	0.00	0.74
McEwen	24	0	0	3	116	1.91	2.60	72.96	0.01	0.72
McEwen	24	0	0	4	116	1.91	3.07	72.96	0.04	0.74
McGrath	25	0	0	1	105	1.81	1.35	71.98	0.03	0.74
McGrath	25	0	0	2	105	1.81	1.95	71.98	0.04	0.78
McGrath	25	0	0	3	105	1.81	2.42	71.98	0.04	0.78
McGrath	25	0	0	4	105	1.81	2.88	71.98	0.02	0.80

Athlete	Sub_Num	Sex	Country	Turn	Mass	Hgt	Time	Distance	HgtofFt	HgtHip
Moton	26	1	0	1	98	1.85	1.43	64.02	0.02	0.80
Moton	26	1	0	2	98	1.85	2.23	64.02	-0.01	0.82
Moton	26	1	0	3	98	1.85	2.88	64.02	0.00	0.83
Moton	26	1	0	4	98	1.85	3.38	64.02	0.00	0.82
Nutter	27	0	0	1	109	1.78	1.40	69.54	0.12	0.69
Nutter	27	0	0	2	109	1.78	2.08	69.54	0.09	0.71
Nutter	27	0	0	3	109	1.78	2.58	69.54	0.11	0.72
Nutter	27	0	0	4	109	1.78	3.05	69.54	0.13	0.73
Parker	28	0	0	1	114	1.82	1.60	73.04	-0.01	0.74
Parker	28	0	0	2	114	1.82	2.32	73.04	0.01	0.71
Parker	28	0	0	3	114	1.82	2.85	73.04	0.01	0.75
Parker	28	0	0	4	114	1.82	3.32	73.04	0.00	0.78
Price	29	1	0	1	84	1.70	1.32	70.34	-0.01	0.68
Price	29	1	0	2	84	1.70	1.97	70.34	0.02	0.71
Price	29	1	0	3	84	1.70	2.45	70.34	0.05	0.74
Price	29	1	0	4	84	1.70	2.90	70.34	0.05	0.74

Athlete	Sub_Num	Sex	Country	Turn	LowPtY	HighPtY	LowPtZ	HighPtZ	TurnRatio	Orbit
Annus	1	0	1	1	-0.40	2.86	0.20	1.61	0.91	21.29
Annus	1	0	1	2	0.16	3.09	0.16	1.95	1.07	31.33
Annus	1	0	1	3	0.57	3.28	0.16	2.16	1.15	38.62
Annus	1	0	1	4	0.98	3.61	0.10	2.30	1.08	38.82
Keil	2	1	1	1	-0.20	2.47	0.32	1.62	1.21	26.86
Keil	2	1	1	2	0.30	2.61	0.17	1.88	1.55	37.58
Keil	2	1	1	3	0.70	2.78	0.06	2.04	1.45	44.18
Keil	2	1	1	4	1.02	3.01	0.05	2.16	1.42	47.60
Kobs	3	0	1	1	-0.50	2.50	0.46	1.73	0.71	23.05
Kobs	3	0	1	2	-0.10	2.59	0.32	2.03	1.00	36.15
Kobs	3	0	1	3	0.52	2.62	0.22	2.35	1.21	46.53
Kobs	3	0	1	4	0.98	2.79	0.12	2.52	1.33	48.27
Konovalov	4	0	1	1	-0.53	2.71	0.33	1.51	0.66	35.79
Konovalov	4	0	1	2	-0.14	2.92	0.11	1.80	1.06	32.84
Konovalov	4	0	1	3	0.28	3.01	0.09	2.05	1.42	38.25
Konovalov	4	0	1	4	0.92	3.24	0.05	2.22	1.55	39.07
Kozmus	5	0	1	1	-0.70	2.62	0.27	1.80	0.82	31.88
Kozmus	5	0	1	2	-0.20	2.81	0.21	1.93	0.94	30.64
Kozmus	5	0	1	3	0.40	3.15	0.17	2.08	0.80	34.94
Kozmus	5	0	1	4	1.05	3.55	0.14	2.15	0.56	35.96
Kuzenkova	6	1	1	1	-0.38	2.50	0.36	1.79	0.78	30.35
Kuzenkova	6	1	1	2	0.18	2.72	0.22	2.03	1.13	37.79
Kuzenkova	6	1	1	3	0.41	2.94	0.12	2.20	1.15	44.63
Kuzenkova	6	1	1	4	0.88	3.21	0.04	2.29	0.88	41.21

Athlete	Sub_Num	Sex	Country	Turn	LowPtY	HighPtY	LowPtZ	HighPtZ	TurnRatio	Orbit
Charfreitag	7	0	1	1	-0.61	2.71	0.17	1.74	0.91	24.44
Charfreitag	7	0	1	2	-0.33	2.98	0.07	1.92	1.13	32.44
Charfreitag	7	0	1	3	0.34	3.24	0.02	2.12	1.14	38.00
Charfreitag	7	0	1	4	0.96	3.53	0.02	2.24	0.93	40.77
Mahon WAC	8	1	1	1	-0.85	2.48	0.38	1.59	0.75	28.05
Mahon WAC	8	1	1	2	-0.33	2.66	0.28	1.89	1.07	28.50
Mahon WAC	8	1	1	3	0.27	2.98	0.16	2.01	1.55	34.19
Mahon WAC	8	1	1	4	0.79	3.21	0.11	2.21	1.38	37.40
Melinte	9	1	1	1	-0.12	2.55	0.08	1.83	1.47	33.68
Melinte	9	1	1	2	0.41	2.73	0.07	2.04	1.31	41.26
Melinte	9	1	1	3	0.83	2.89	0.06	2.29	3.17	48.54
Melinte	9	1	1	4	0.90	3.14	-0.01	2.41	1.83	47.54
Montebrun	10	1	1	1	-0.65	2.75	0.15	1.84	0.86	69.79
Montebrun	10	1	1	2	-0.08	2.81	0.10	2.06	1.31	35.39
Montebrun	10	1	1	3	0.43	3.02	0.08	2.21	1.55	39.58
Montebrun	10	1	1	4	0.06	3.33	0.06	2.34	1.42	40.40
Moreno	11	1	1	1	-0.59	2.22	0.49	1.59	2.56	23.11
Moreno	11	1	1	2	-0.42	2.41	0.11	1.94	2.15	42.64
Moreno	11	1	1	3	0.39	2.73	0.10	2.10	1.17	48.62
Moreno	11	1	1	4	0.84	3.10	0.05	2.19	0.70	47.93
Murofushi	12	0	1	1	0.08	1.97	0.24	1.76	1.06	44.89
Murofushi	12	0	1	2	0.30	2.28	0.19	1.94	1.15	42.18
Murofushi	12	0	1	3	0.64	2.75	0.18	2.06	1.36	42.16
Murofushi	12	0	1	4	0.92	3.26	0.11	2.17	1.15	38.79
Sekochova	13	1	1	1	-0.20	2.54	0.04	1.40	1.19	23.57

Athlete	Sub_Num	Sex	Country	Turn	LowPtY	HighPtY	LowPtZ	HighPtZ	TurnRatio	Orbit
Sekochova	13	1	1	2	0.39	2.69	0.09	1.72	1.07	35.48
Sekochova	13	1	1	3	0.49	2.94	0.12	1.90	1.08	41.14
Sekochova	13	1	1	4	1.36	3.25	0.07	2.05	0.80	44.81
Skolimowska	14	1	1	1	-0.29	2.78	0.27	1.72	1.17	45.66
Skolimowska	14	1	1	2	0.28	2.75	0.10	2.08	0.88	39.64
Skolimowska	14	1	1	3	0.75	2.79	0.04	2.34		
Skvaruk	15	0	1	1	-0.63	2.72	0.32	1.53	0.73	30.93
Skvaruk	15	0	1	2	-0.02	2.84	0.17	1.84	1.13	33.27
Skvaruk	15	0	1	3	0.45	2.96	0.11	2.05	1.55	40.23
Skvaruk	15	0	1	4	1.16	3.19	0.09	2.25	1.42	42.14
Tikhon	16	0	1	1	-0.75	2.59	0.29	1.86	0.84	41.63
Tikhon	16	0	1	2	-0.19	2.74	0.19	2.03	1.00	38.23
Tikhon	16	0	1	3	0.18	3.00	0.07	2.13	1.00	39.34
Tikhon	16	0	1	4	0.70	3.42	0.02	2.18	0.93	33.56
Ellerbe	17	1	0	1	-0.13	2.62	0.33	2.03	1.25	32.60
Ellerbe	17	1	0	2	0.61	2.91	0.25	2.23	1.21	42.74
Ellerbe	17	1	0	3	1.10	3.30	0.15	2.39	1.09	46.00
Campbell	18	1	0	1	-0.28	2.61	0.08	1.75	1.00	26.28
Campbell	18	1	0	2	0.14	3.03	0.16	1.86	0.89	31.11
Campbell	18	1	0	3	0.55	3.45	0.17	1.95	1.21	32.45
Campbell	18	1	0	4	0.08	3.69	0.08	2.12	0.67	36.17
Dickerson	19	1	0	1	-1.27	3.06	0.38	1.82	0.79	19.00
Dickerson	19	1	0	2	-0.57	3.26	0.28	2.03	1.07	24.94
Dickerson	19	1	0	3	-0.02	3.40	0.19	2.21	1.55	31.10
Dickerson	19	1	0	4	0.13	3.58	0.16	2.37	1.73	31.02

Athlete	**Sub_Num**	**Sex**	**Country**	**Turn**	**LowPtY**	**HighPtY**	**LowPtZ**	**HighPtZ**	**TurnRatio**	**Orbit**
Freeman	20	0	0	1	-0.81	2.55	0.28	1.90	0.88	30.03
Freeman	20	0	0	2	-0.54	2.71	0.16	2.32	0.84	44.21
Freeman	20	0	0	3	0.18	3.01	0.06	2.48	0.93	49.61
Freeman	20	0	0	4	0.45	3.35	0.02	2.58	1.00	38.37
Gilreath	21	1	0	1	-0.65	2.29	0.31	1.69	0.73	23.90
Gilreath	21	1	0	2	-0.05	2.63	0.14	1.92	1.06	33.51
Gilreath	21	1	0	3	0.59	2.96	0.07	2.19	1.13	42.24
Gilreath	21	1	0	4	1.11	3.47	0.08	2.37	1.33	43.81
MacKay	22	0	0	1	-0.78	2.54	0.37	1.54	0.92	36.77
MacKay	22	0	0	2	-0.24	2.75	0.32	1.91	1.14	29.10
MacKay	22	0	0	3	0.21	2.95	0.22	2.16	1.29	36.67
MacKay	22	0	0	4	0.81	3.31	0.16	2.34	0.70	35.27
Mahon	23	1	0	1	-0.23	2.15	0.30	1.59	0.82	79.88
Mahon	23	1	0	2	0.05	2.31	0.22	1.92	1.00	43.03
Mahon	23	1	0	3	0.48	2.70	0.12	2.09	1.23	43.75
Mahon	23	1	0	4	0.86	3.07	0.08	2.27	1.45	34.51
McEwen	24	0	0	1	-0.96	1.98	0.30	1.93	1.00	34.80
McEwen	24	0	0	2	-0.90	2.16	0.28	1.72	1.06	27.57
McEwen	24	0	0	3	-0.15	2.58	0.66	1.74	1.33	32.02
McEwen	24	0	0	4	-0.72	2.81	0.30	1.90	1.07	30.84
McGrath	25	0	0	1	-0.93	2.41	0.44	1.73	1.06	44.39
McGrath	25	0	0	2	-0.51	2.57	0.45	2.10	1.00	29.69
McGrath	25	0	0	3	-0.03	2.77	0.24	2.30	1.15	37.70
McGrath	25	0	0	4	0.35	3.06	0.10	2.42	0.82	43.92
Moton	26	1	0	1	-0.40	2.26	0.08	1.97	1.19	32.32

Athlete	Sub_Num	Sex	Country	Turn	LowPtY	HighPtY	LowPtZ	HighPtZ	TurnRatio	Orbit
Moton	26	1	0	2	0.01	2.30	0.11	2.38	1.86	45.98
Moton	26	1	0	3	0.64	2.58	0.11	2.51	1.58	51.54
Moton	26	1	0	4	0.11	2.97	0.11	2.51	1.00	49.48
Nutter	27	0	0	1	-0.45	2.33	0.17	1.78	1.00	45.02
Nutter	27	0	0	2	0.04	2.46	0.12	1.96	0.88	38.36
Nutter	27	0	0	3	0.55	2.79	0.07	2.07	0.93	42.09
Nutter	27	0	0	4	1.09	3.31	0.09	2.11	0.93	33.79
Parker	28	0	0	1	-0.68	2.43	0.53	1.37	0.90	46.69
Parker	28	0	0	2	-0.09	2.69	0.28	1.74	1.07	45.37
Parker	28	0	0	3	0.53	2.98	0.15	2.03	1.55	57.69
Parker	28	0	0	4	0.69	3.24	0.07	2.24	1.13	55.47
Price	29	1	0	1	-0.58	2.31	0.34	1.66	0.95	45.28
Price	29	1	0	2	-0.02	2.42	0.20	2.01	1.07	38.98
Price	29	1	0	3	0.51	2.72	0.12	2.17	1.25	45.13
Price	29	1	0	4	1.07	3.18	0.01	2.24	1.07	35.71

Athlete	Sub_Num	Sex	Country	Turn	AvgRad	MinRad	MaxRad	ChanRad	TurnTime
Annus	1	0	1	1	1.49	0.84	2.73	1.89	0.70
Annus	1	0	1	2	1.71	1.10	2.79	1.70	0.52
Annus	1	0	1	3	1.62	1.23	2.27	0.97	0.47
Annus	1	0	1	4	1.74	1.34	2.34	0.58	0.45
Keil	2	1	1	1	1.62	1.29	1.97	0.68	0.52
Keil	2	1	1	2	1.54	1.27	1.77	0.50	0.47
Keil	2	1	1	3	1.53	1.30	1.76	0.45	0.45
Keil	2	1	1	4	1.54	1.31	2.07	0.36	0.48
Kobs	3	0	1	1	1.71	1.37	2.10	0.73	0.88
Kobs	3	0	1	2	1.63	1.31	1.95	0.64	0.63
Kobs	3	0	1	3	1.54	1.28	1.82	0.54	0.52
Kobs	3	0	1	4	1.52	1.27	2.34	0.27	0.40
Konovalov	4	0	1	1	1.77	1.43	2.26	0.83	0.88
Konovalov	4	0	1	2	1.73	1.48	2.29	0.82	0.58
Konovalov	4	0	1	3	1.66	1.43	2.06	0.63	0.48
Konovalov	4	0	1	4	1.63	1.42	2.11	0.48	0.40
Kozmus	5	0	1	1	1.79	1.25	2.22	0.97	0.67
Kozmus	5	0	1	2	1.75	1.26	2.41	1.16	0.52
Kozmus	5	0	1	3	1.67	1.18	2.43	1.19	0.45
Kozmus	5	0	1	4	1.56	1.03	2.36	1.09	0.47
Kuzenkova	6	1	1	1	1.65	1.42	1.96	0.54	0.68
Kuzenkova	6	1	1	2	1.63	1.46	1.91	0.45	0.53
Kuzenkova	6	1	1	3	1.59	1.41	1.83	0.41	0.47
Kuzenkova	6	1	1	4	1.58	1.39	2.15	0.37	0.43

Athlete	Sub_Num	Sex	Country	Turn	AvgRad	MinRad	MaxRad	ChanRad	TurnTime
Charfreitag	7	0	1	1	1.85	1.57	2.10	0.53	0.70
Charfreitag	7	0	1	2	1.80	1.54	2.12	0.58	0.57
Charfreitag	7	0	1	3	1.75	1.45	2.05	0.60	0.50
Charfreitag	7	0	1	4	1.72	1.37	2.37	0.67	0.40
Mahon WAC	8	1	1	1	1.78	1.44	2.08	0.64	0.70
Mahon WAC	8	1	1	2	1.73	1.43	2.04	0.61	0.52
Mahon WAC	8	1	1	3	1.67	1.49	1.95	0.46	0.47
Mahon WAC	8	1	1	4	1.67	1.41	2.52	0.53	0.43
Melinte	9	1	1	1	1.68	1.36	1.97	0.61	0.62
Melinte	9	1	1	2	1.64	1.37	1.82	0.45	0.50
Melinte	9	1	1	3	1.60	1.33	1.74	0.42	0.42
Melinte	9	1	1	4	1.62	1.43	2.24	0.33	0.50
Montebrun	10	1	1	1	1.83	1.46	2.32	0.86	0.65
Montebrun	10	1	1	2	1.77	1.55	2.04	0.49	0.50
Montebrun	10	1	1	3	1.73	1.57	1.99	0.41	0.47
Montebrun	10	1	1	4	1.70	1.41	2.26	0.52	0.40
Moreno	11	1	1	1	1.67	1.27	2.11	0.84	0.53
Moreno	11	1	1	2	1.68	1.22	2.07	0.84	0.68
Moreno	11	1	1	3	1.57	1.11	1.87	0.76	0.43
Moreno	11	1	1	4	1.58	1.15	2.10	0.77	0.47
Murofushi	12	0	1	1	1.63	0.71	3.30	2.58	0.62
Murofushi	12	0	1	2	1.55	1.01	2.21	1.20	0.47
Murofushi	12	0	1	3	1.54	1.24	1.85	0.61	0.43
Murofushi	12	0	1	4	1.61	1.38	2.29	0.31	0.40
Sekochova	13	1	1	1	1.67	1.33	1.89	0.55	0.58

Athlete	Sub_Num	Sex	Country	Turn	AvgRad	MinRad	MaxRad	ChanRad	TurnTime
Sekochova	13	1	1	2	1.56	1.31	1.79	0.47	0.52
Sekochova	13	1	1	3	1.50	1.27	1.67	0.40	0.42
Sekochova	13	1	1	4	1.52	1.27	2.14	0.35	0.40
Skolimowska	14	1	1	1	1.72	1.41	2.08	0.67	0.65
Skolimowska	14	1	1	2	1.66	1.45	1.82	0.37	0.53
Skolimowska	14	1	1	3	1.66	1.48	2.13	0.36	0.43
Skvaruk	15	0	1	1	1.74	1.46	2.13	0.68	0.87
Skvaruk	15	0	1	2	1.69	1.44	2.23	0.80	0.57
Skvaruk	15	0	1	3	1.58	1.25	2.03	0.77	0.47
Skvaruk	15	0	1	4	1.50	1.20	1.95	0.69	0.40
Tikhon	16	0	1	1	1.76	1.36	2.15	0.78	0.58
Tikhon	16	0	1	2	1.70	1.40	2.10	0.70	0.47
Tikhon	16	0	1	3	1.68	1.45	2.03	0.58	0.43
Tikhon	16	0	1	4	1.69	1.34	2.17	0.73	0.40
Ellerbe	17	1	0	1	1.76	1.29	2.40	1.11	0.60
Ellerbe	17	1	0	2	1.68	1.20	2.27	1.07	0.52
Ellerbe	17	1	0	3	1.67	1.43	2.48	0.31	0.42
Campbell	18	1	0	1	1.75	1.38	2.12	0.74	0.60
Campbell	18	1	0	2	1.76	1.61	2.19	0.58	0.57
Campbell	18	1	0	3	1.73	1.54	2.07	0.54	0.52
Campbell	18	1	0	4	1.70	1.48	2.18	0.70	0.43
Dickerson	19	1	0	1	2.09	0.73	3.88	3.14	0.57
Dickerson	19	1	0	2	2.07	1.02	3.62	2.60	0.52
Dickerson	19	1	0	3	1.96	1.04	3.18	2.14	0.47
Dickerson	19	1	0	4	1.87	1.20	2.84	1.63	0.45

Athlete	Sub_Num	Sex	Country	Turn	AvgRad	MinRad	MaxRad	ChanRad	TurnTime
Freeman	20	0	0	1	1.80	1.57	2.10	0.53	0.75
Freeman	20	0	0	2	1.81	1.59	2.36	0.76	0.58
Freeman	20	0	0	3	1.72	1.57	2.20	0.63	0.45
Freeman	20	0	0	4	1.78	1.59	2.28	0.48	0.53
Gilreath	21	1	0	1	1.10	0.18	2.56	2.38	0.75
Gilreath	21	1	0	2	1.29	0.18	3.05	2.86	0.58
Gilreath	21	1	0	3	1.64	1.13	2.44	1.21	0.53
Gilreath	21	1	0	4	1.23	0.45	2.20	1.24	0.40
MacKay	22	0	0	1	1.84	1.47	2.75	1.28	0.80
MacKay	22	0	0	2	1.74	1.56	2.03	0.47	0.50
MacKay	22	0	0	3	1.75	1.55	2.07	0.49	0.53
MacKay	22	0	0	4	1.73	1.57	2.17	0.37	0.65
Mahon	23	1	0	1	1.68	0.88	2.53	1.65	0.67
Mahon	23	1	0	2	1.63	1.04	2.27	1.23	0.53
Mahon	23	1	0	3	1.60	1.19	2.10	0.91	0.47
Mahon	23	1	0	4	1.61	1.12	2.07	0.95	0.42
McEwen	24	0	0	1	1.82	1.33	2.49	1.17	0.70
McEwen	24	0	0	2	1.76	1.53	2.02	0.49	0.55
McEwen	24	0	0	3	1.73	1.49	2.13	0.64	0.47
McEwen	24	0	0	4	1.77	1.46	2.53	0.70	0.52
McGrath	25	0	0	1	1.69	1.49	2.07	0.58	0.58
McGrath	25	0	0	2	1.67	1.52	1.84	0.32	0.47
McGrath	25	0	0	3	1.67	1.53	1.89	0.37	0.47
McGrath	25	0	0	4	1.69	1.54	2.04	0.29	0.52
Moton	26	1	0	1	1.70	1.52	2.02	0.49	0.80

Athlete	Sub_Num	Sex	Country	Turn	AvgRad	MinRad	MaxRad	ChanRad	TurnTime
Moton	26	1	0	2	1.66	1.37	2.09	0.72	0.65
Moton	26	1	0	3	1.61	1.36	1.98	0.62	0.50
Moton	26	1	0	4	1.51	1.27	2.18	0.28	0.38
Nutter	27	0	0	1	1.67	1.18	2.52	1.34	0.67
Nutter	27	0	0	2	1.64	1.39	2.19	0.80	0.50
Nutter	27	0	0	3	1.64	1.14	2.23	0.81	0.48
Nutter	27	0	0	4	1.63	1.37	1.95	0.55	0.45
Parker	28	0	0	1	1.70	1.40	1.97	0.58	0.67
Parker	28	0	0	2	1.67	1.42	1.86	0.44	0.52
Parker	28	0	0	3	1.65	1.42	1.97	0.53	0.47
Parker	28	0	0	4	1.67	1.42	2.37	0.42	0.53
Price	29	1	0	1	1.62	1.44	1.86	0.42	0.65
Price	29	1	0	2	1.54	1.29	1.95	0.67	0.48
Price	29	1	0	3	1.52	1.22	2.00	0.77	0.45
Price	29	1	0	4	1.50	1.08	2.03	0.86	0.38

Table 9. Subject Data for Turn and Stance Variables

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Annus	1	0	1	0	0	102	1.94	0.02	82.10	0.00	0.00	0.00
Annus	1	0	1	1	1	102	1.94	1.58	82.10	81.00	8.17	0.33
Annus	1	0	1	1	2	102	1.94	1.92	82.10	125.87	4.25	0.37
Annus	1	0	1	2	1	102	1.94	2.28	82.10	88.15	12.49	0.27
Annus	1	0	1	2	2	102	1.94	2.55	82.10	103.11	5.79	0.25
Annus	1	0	1	3	1	102	1.94	2.80	82.10	83.61	24.82	0.25
Annus	1	0	1	3	2	102	1.94	3.05	82.10	107.34	8.79	0.22
Annus	1	0	1	4	1	102	1.94	3.27	82.10	92.35	33.57	0.23
Annus	1	0	1	4	2	102	1.94	3.50	82.10	74.92	173.73	0.22
Annus	1	0	1	5	2	102	1.94	3.72	82.10	0.00	7.60	0.00
Keil	2	1	1	0	0	70	175	0.02	67.78	0.00	0.00	0.00
Keil	2	1	1	1	1	70	175	1.13	67.78	91.09	4.69	0.28
Keil	2	1	1	1	2	70	175	1.42	67.78	109.00	1.18	0.23
Keil	2	1	1	2	1	70	175	1.65	67.78	98.19	15.07	0.28
Keil	2	1	1	2	2	70	175	1.93	67.78	85.55	12.25	0.18
Keil	2	1	1	3	1	70	175	2.12	67.78	93.45	0.62	0.27
Keil	2	1	1	3	2	70	175	2.38	67.78	87.50	6.63	0.18
Keil	2	1	1	4	1	70	175	2.57	67.78	81.17	24.07	0.28
Keil	2	1	1	4	2	70	175	2.85	67.78	85.01	154.19	0.20
Keil	2	1	1	5	2	70	175	3.05	67.78	0.00	2.47	0.00
Kobs	3	0	1	0	0	118	1.96	0.02	74.18	0.00	0.00	0.00
Kobs	3	0	1	1	1	118	1.96	1.88	74.18	83.79	23.64	0.37
Kobs	3	0	1	1	2	118	1.96	2.25	74.18	105.01	39.36	0.52
Kobs	3	0	1	2	1	118	1.96	2.77	74.18	94.10	16.17	0.32

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Kobs	3	0	1	1	2	118	1.96	2.25	74.18	105.01	39.36	0.52
Kobs	3	0	1	2	1	118	1.96	2.77	74.18	94.10	16.17	0.32
Kobs	3	0	1	2	2	118	1.96	3.08	74.18	94.47	46.38	0.32
Kobs	3	0	1	3	1	118	1.96	3.40	74.18	90.49	25.30	0.28
Kobs	3	0	1	3	2	118	1.96	3.68	74.18	108.70	38.89	0.23
Kobs	3	0	1	4	1	118	1.96	3.92	74.18	91.35	27.97	0.27
Kobs	3	0	1	4	2	118	1.96	4.18	74.18	103.68	164.86	0.20
Kobs	3	0	1	5	2	118	1.96	4.38	74.18	0.00	10.56	0.00
Konovalov	4	0	1	0	0	106	1.92	0.02	78.57	0.00	0.00	0.00
Konovalov	4	0	1	1	1	106	1.92	2.15	78.57	114.55	6.57	0.35
Konovalov	4	0	1	1	2	106	1.92	2.50	78.57	97.66	60.84	0.53
Konovalov	4	0	1	2	1	106	1.92	3.03	78.57	108.71	8.52	0.30
Konovalov	4	0	1	2	2	106	1.92	3.33	78.57	124.60	18.83	0.28
Konovalov	4	0	1	3	1	106	1.92	3.62	78.57	105.76	10.60	0.28
Konovalov	4	0	1	3	2	106	1.92	3.90	78.57	120.37	20.88	0.20
Konovalov	4	0	1	4	1	106	1.92	4.10	78.57	104.24	15.91	0.28
Konovalov	4	0	1	4	2	106	1.92	4.38	78.57	107.58	139.14	0.18
Konovalov	4	0	1	5	2	106	1.92	4.57	78.57	0.00	12.23	0.00
Kozmus	5	0	1	0	0	106	1.88	0.02	78.59	0.00	0.00	0.00
Kozmus	5	0	1	1	1	106	1.88	0.87	78.59	106.46	6.05	0.30
Kozmus	5	0	1	1	2	106	1.88	1.17	78.59	136.05	15.35	0.37
Kozmus	5	0	1	2	1	106	1.88	1.53	78.59	103.81	8.90	0.25
Kozmus	5	0	1	2	2	106	1.88	1.78	78.59	127.12	12.51	0.27
Kozmus	5	0	1	3	1	106	1.88	2.05	78.59	95.07	17.45	0.20
Kozmus	5	0	1	3	2	106	1.88	2.25	78.59	120.53	11.32	0.25

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Kozmus	5	0	1	4	1	106	1.88	2.50	78.59	100.33	9.11	0.17
Kozmus	5	0	1	4	2	106	1.88	2.67	78.59	92.17	150.91	0.30
Kozmus	5	0	1	5	2	106	1.88	2.97	78.59	0.00	20.93	0.00
Kuzenkova	6	1	1	0	0	76	1.76	0.02	71.16	0.00	0.00	0.00
Kuzenkova	6	1	1	1	1	76	1.76	1.38	71.16	94.00	10.71	0.30
Kuzenkova	6	1	1	1	2	76	1.76	1.68	71.16	130.06	12.97	0.38
Kuzenkova	6	1	1	2	1	76	1.76	2.07	71.16	96.76	21.69	0.28
Kuzenkova	6	1	1	2	2	76	1.76	2.35	71.16	108.55	29.55	0.25
Kuzenkova	6	1	1	3	1	76	1.76	2.60	71.16	104.84	27.81	0.25
Kuzenkova	6	1	1	3	2	76	1.76	2.85	71.16	116.67	16.32	0.22
Kuzenkova	6	1	1	4	1	76	1.76	3.07	71.16	97.94	17.39	0.23
Kuzenkova	6	1	1	4	2	76	1.76	3.30	71.16	107.09	166.25	0.27
Kuzenkova	6	1	1	5	2	76	1.76	3.57	71.16	0.00	8.28	0.00
Charfreitag	7	0	1	0	0	117	1.91	0.02	78.59	0.00	0.00	0.00
Charfreitag	7	0	1	1	1	117	1.91	1.35	78.59	94.94	12.97	0.33
Charfreitag	7	0	1	1	2	117	1.91	1.68	78.59	99.95	20.85	0.37
Charfreitag	7	0	1	2	1	117	1.91	2.05	78.59	91.87	23.56	0.30
Charfreitag	7	0	1	2	2	117	1.91	2.35	78.59	111.52	27.69	0.27
Charfreitag	7	0	1	3	1	117	1.91	2.62	78.59	91.39	31.40	0.27
Charfreitag	7	0	1	3	2	117	1.91	2.88	78.59	109.50	19.39	0.23
Charfreitag	7	0	1	4	1	117	1.91	3.12	78.59	94.19	48.24	0.23
Charfreitag	7	0	1	4	2	117	1.91	3.35	78.59	114.52	160.90	0.25
Charfreitag	7	0	1	5	2	117	1.91	3.60	78.59	0.00	15.94	0.00
Mahon WAC	8	1	1	0	0	82	1.81	0.02	66.94	0.00	0.00	0.00
Mahon WAC	8	1	1	1	1	82	1.81	1.08	66.94	88.63	1.99	0.30

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Mahon WAC	8	1	1	1	2	82	1.81	1.38	66.94	123.93	10.65	0.40
Mahon WAC	8	1	1	2	1	82	1.81	1.78	66.94	92.97	13.15	0.27
Mahon WAC	8	1	1	2	2	82	1.81	2.05	66.94	117.69	28.65	0.25
Mahon WAC	8	1	1	3	1	82	1.81	2.30	66.94	89.64	21.04	0.28
Mahon WAC	8	1	1	3	2	82	1.81	2.58	66.94	109.34	33.63	0.18
Mahon WAC	8	1	1	4	1	82	1.81	2.77	66.94	82.03	7.56	0.30
Mahon WAC	8	1	1	4	2	82	1.81	3.07	66.94	102.38	125.24	0.22
Mahon WAC	8	1	1	5	2	82	1.81	3.28	66.94	0.00	15.32	0.00
Melinte	9	1	1	0	0	84	1.7	0.02	69.27	0.00	0.00	0.00
Melinte	9	1	1	1	1	84	1.7	1.17	69.27	95.59	1.65	0.37
Melinte	9	1	1	1	2	84	1.7	1.53	69.27	121.88	15.66	0.25
Melinte	9	1	1	2	1	84	1.7	1.78	69.27	70.59	47.63	0.28
Melinte	9	1	1	2	2	84	1.7	2.07	69.27	102.98	21.91	0.22
Melinte	9	1	1	3	1	84	1.7	2.28	69.27	76.41	33.19	0.32
Melinte	9	1	1	3	2	84	1.7	2.60	69.27	124.86	1.28	0.10
Melinte	9	1	1	4	1	84	1.7	2.70	69.27	82.29	11.54	0.37
Melinte	9	1	1	4	2	84	1.7	3.07	69.27	142.81	90.20	0.20
Melinte	9	1	1	5	2	84	1.7	3.27	69.27	0.00	21.95	0.00
Montebrun	10	1	1	0	0	92	1.75	0.02	68.88	0.00	0.00	0.00
Montebrun	10	1	1	1	1	92	1.75	1.40	68.88	101.32	11.58	0.30
Montebrun	10	1	1	1	2	92	1.75	1.70	68.88	115.44	11.34	0.35
Montebrun	10	1	1	2	1	92	1.75	2.05	68.88	101.31	7.93	0.28
Montebrun	10	1	1	2	2	92	1.75	2.33	68.88	114.38	14.19	0.22
Montebrun	10	1	1	3	1	92	1.75	2.55	68.88	95.58	31.20	0.28
Montebrun	10	1	1	3	2	92	1.75	2.83	68.88	112.63	14.47	0.18

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Montebrun	10	1	1	4	1	92	1.75	3.02	68.88	100.17	7.23	0.28
Montebrun	10	1	1	4	2	92	1.75	3.30	68.88	108.50	108.52	0.20
Montebrun	10	1	1	5	2	92	1.75	3.50	68.88	0.00	18.53	
Moreno	11	1	1	0	0	71	1.68	0.02	73.42	0.00	0.00	0.00
Moreno	11	1	1	1	1	71	1.68	1.43	73.42	94.01	24.83	0.38
Moreno	11	1	1	1	2	71	1.68	1.82	73.42	111.78	35.27	0.15
Moreno	11	1	1	2	1	71	1.68	1.97	73.42	118.37	21.95	0.47
Moreno	11	1	1	2	2	71	1.68	2.43	73.42	91.23	60.55	0.22
Moreno	11	1	1	3	1	71	1.68	2.65	73.42	94.32	40.27	0.23
Moreno	11	1	1	3	2	71	1.68	2.88	73.42	95.38	56.70	0.20
Moreno	11	1	1	4	1	71	1.68	3.08	73.42	100.69	42.39	0.23
Moreno	11	1	1	4	2	71	1.68	3.32	73.42	73.40	125.96	0.33
Moreno	11	1	1	5	2	71	1.68	3.65	73.42	0.00	28.64	0.00
Murofushi	12	0	1	0	0	96	1.87	0.02	79.12	0.00	0.00	0.00
Murofushi	12	0	1	1	1	96	1.87	0.98	79.12	81.71	5.97	0.32
Murofushi	12	0	1	1	2	96	1.87	1.30	79.12	103.28	12.66	0.30
Murofushi	12	0	1	2	1	96	1.87	1.60	79.12	74.81	25.59	0.25
Murofushi	12	0	1	2	2	96	1.87	1.85	79.12	106.83	17.68	0.22
Murofushi	12	0	1	3	1	96	1.87	2.07	79.12	79.71	7.65	0.25
Murofushi	12	0	1	3	2	96	1.87	2.32	79.12	106.48	4.22	0.18
Murofushi	12	0	1	4	1	96	1.87	2.50	79.12	85.32	16.61	0.25
Murofushi	12	0	1	4	2	96	1.87	2.75	79.12	106.19	149.03	0.22
Murofushi	12	0	1	5	2	96	1.87	2.97	79.12	0.00	18.52	0.00
Sekochova	13	1	1	0	0	66	1.64	0.02	66.46	0.00	0.00	0.00
Sekochova	13	1	1	1	1	66	1.64	1.23	66.46	109.63	17.57	0.32

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Sekochova	13	1	1	1	2	66	1.64	1.55	66.46	118.65	16.88	0.27
Sekochova	13	1	1	2	1	66	1.64	1.82	66.46	113.59	13.17	0.27
Sekochova	13	1	1	2	2	66	1.64	2.08	66.46	112.55	31.63	0.25
Sekochova	13	1	1	3	1	66	1.64	2.33	66.46	96.54	24.01	0.22
Sekochova	13	1	1	3	2	66	1.64	2.55	66.46	96.15	24.55	0.20
Sekochova	13	1	1	4	1	66	1.64	2.75	66.46	99.32	8.35	0.20
Sekochova	13	1	1	4	2	66	1.64	2.95	66.46	93.44	167.64	0.25
Sekochova	13	1	1	5	2	66	1.64	3.20	66.46	0.00	1.28	0.00
Skolimowska	14	1	1	0	0	105	1.81	0.02	61.46	0.00	0.00	0.00
Skolimowska	14	1	1	1	1	105	1.81	1.25	61.46	103.57	12.05	0.35
Skolimowska	14	1	1	1	2	105	1.81	1.60	61.46	115.45	5.67	0.30
Skolimowska	14	1	1	2	1	105	1.81	1.90	61.46	91.93	17.60	0.25
Skolimowska	14	1	1	2	2	105	1.81	2.15	61.46	100.82	8.80	0.28
Skolimowska	14	1	1	3	1	105	1.81	2.43	61.46	91.00	7.77	0.23
Skolimowska	14	1	1	3	2	105	1.81	2.67	61.46	99.10	2.38	0.00
Skolimowska	14	1	1	5	2	105	1.81	2.93	61.46	0.00	29.73	0.00
Skvaruk	15	0	1	0	0	103	1.86	0.02	78.76	0.00	0.00	0.00
Skvaruk	15	0	1	1	1	103	1.86	1.98	78.76	116.67	14.94	0.37
Skvaruk	15	0	1	1	2	103	1.86	2.35	78.76	105.34	41.76	0.50
Skvaruk	15	0	1	2	1	103	1.86	2.85	78.76	106.66	6.64	0.30
Skvaruk	15	0	1	2	2	103	1.86	3.15	78.76	111.13	40.48	0.27
Skvaruk	15	0	1	3	1	103	1.86	3.42	78.76	110.76	10.53	0.28
Skvaruk	15	0	1	3	2	103	1.86	3.70	78.76	118.76	28.76	0.18
Skvaruk	15	0	1	4	1	103	1.86	3.88	78.76	103.59	21.08	0.28
Skvaruk	15	0	1	4	2	103	1.86	4.17	78.76	119.32	140.69	0.20

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Skvaruk	15	0	1	5	2	103	1.86	4.37	78.76	0.00	12.01	0.00
Tikhon	16	0	1	0	0	110	1.86	0.02	80.84	0.00	0.00	0.00
Tikhon	16	0	1	1	1	110	1.86	1.22	80.84	110.97	1.01	0.27
Tikhon	16	0	1	1	2	110	1.86	1.48	80.84	104.91	26.90	0.32
Tikhon	16	0	1	2	1	110	1.86	1.80	80.84	111.35	19.44	0.23
Tikhon	16	0	1	2	2	110	1.86	2.03	80.84	117.09	38.99	0.23
Tikhon	16	0	1	3	1	110	1.86	2.27	80.84	116.84	21.38	0.22
Tikhon	16	0	1	3	2	110	1.86	2.48	80.84	120.65	31.19	0.22
Tikhon	16	0	1	4	1	110	1.86	2.70	80.84	112.57	13.27	0.22
Tikhon	16	0	1	4	2	110	1.86	2.92	80.84	111.91	176.22	0.23
Tikhon	16	0	1	5	2	110	1.86	3.15	80.84	0.00	19.20	0.00
Ellerbe	17	1	0	0	0	109	1.88	0.02	66.76	0.00	0.00	0.00
Ellerbe	17	1	0	1	1	109	1.88	0.32	66.76	99.24	9.76	0.33
Ellerbe	17	1	0	1	2	109	1.88	0.65	66.76	104.06	16.68	0.27
Ellerbe	17	1	0	2	1	109	1.88	0.92	66.76	93.22	10.49	0.28
Ellerbe	17	1	0	2	2	109	1.88	1.20	66.76	91.99	30.41	0.23
Ellerbe	17	1	0	3	1	109	1.88	1.43	66.76	93.09	4.37	0.27
Ellerbe	17	1	0	3	2	109	1.88	1.70	66.76	86.71	27.85	0.28
Ellerbe	17	1	0	5	2	109	1.88	1.88	66.76	0.00	23.64	0.00
Campbell	18	1	0	0	0	91	1.7	0.02	64.02	0.00	0.00	0.00
Campbell	18	1	0	1	1	91	1.7	1.08	64.02	92.77	0.15	0.30
Campbell	18	1	0	1	2	91	1.7	1.38	64.02	94.69	3.29	0.30
Campbell	18	1	0	2	1	91	1.7	1.68	64.02	83.12	35.42	0.27
Campbell	18	1	0	2	2	91	1.7	1.95	64.02	105.01	27.84	0.30
Campbell	18	1	0	3	1	91	1.7	2.25	64.02	89.18	25.91	0.28

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Campbell	18	1	0	3	2	91	1.7	2.53	64.02	102.66	40.97	0.23
Campbell	18	1	0	4	1	91	1.7	2.77	64.02	85.54	18.22	0.20
Campbell	18	1	0	4	2	91	1.7	2.97	64.02	113.44	27.39	0.32
Campbell	18	1	0	5	2	91	1.7	3.27	64.02	0.00	16.50	0.00
Dickerson	19	1	0	0	0	100	1.75	0.02	65.58	0.00	0.00	0.00
Dickerson	19	1	0	1	1	100	1.75	1.40	65.58	101.05	5.15	0.30
Dickerson	19	1	0	1	2	100	1.75	1.65	65.58	102.43	5.78	0.33
Dickerson	19	1	0	2	1	100	1.75	1.97	65.58	110.19	13.20	0.25
Dickerson	19	1	0	2	2	100	1.75	2.23	65.58	106.63	36.22	0.28
Dickerson	19	1	0	3	1	100	1.75	2.48	65.58	99.31	3.00	0.27
Dickerson	19	1	0	3	2	100	1.75	2.77	65.58	114.12	20.94	0.18
Dickerson	19	1	0	4	1	100	1.75	2.95	65.58	76.76	18.20	0.28
Dickerson	19	1	0	4	2	100	1.75	3.27	65.58	128.61	93.85	0.17
Dickerson	19	1	0	5	2	100	1.75	3.45	65.58	0.00	31.85	0.00
Freeman	20	0	0	0	0	146	1.96	0.02	70.08	0.00	0.00	0.00
Freeman	20	0	0	1	1	146	1.96	1.22	70.08	91.78	3.62	0.35
Freeman	20	0	0	1	2	146	1.96	1.57	70.08	70.76	55.16	0.40
Freeman	20	0	0	2	1	146	1.96	1.95	70.08	94.48	13.63	0.27
Freeman	20	0	0	2	2	146	1.96	2.23	70.08	74.92	54.86	0.32
Freeman	20	0	0	3	1	146	1.96	2.55	70.08	104.55	9.56	0.22
Freeman	20	0	0	3	2	146	1.96	2.77	70.08	84.13	56.51	0.23
Freeman	20	0	0	4	1	146	1.96	3.00	70.08	97.58	11.89	0.27
Freeman	20	0	0	4	2	146	1.96	3.27	70.08	78.30	139.04	0.27
Freeman	20	0	0	5	2	146	1.96	3.52	70.08		2.64	0.00
Gilreath	21	1	0	0	0	91	1.78	0.02	64.83	0.00	0.00	0.00

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Gilreath	21	1	0	1	1	91	1.78	1.57	64.83	92.24	3.02	0.32
Gilreath	21	1	0	1	2	91	1.78	1.88	64.83	86.75	15.35	0.43
Gilreath	21	1	0	2	1	91	1.78	2.32	64.83	85.59	2.09	0.30
Gilreath	21	1	0	2	2	91	1.78	2.62	64.83	97.82	30.00	0.28
Gilreath	21	1	0	3	1	91	1.78	2.90	64.83	75.90	15.93	0.28
Gilreath	21	1	0	3	2	91	1.78	3.18	64.83	89.95	29.15	0.25
Gilreath	21	1	0	4	1	91	1.78	3.43	64.83	81.42	9.25	0.27
Gilreath	21	1	0	4	2	91	1.78	3.70	64.83	89.37	153.12	0.22
Gilreath	21	1	0	5	2	91	1.78	3.90	64.83	0.00	30.00	0.00
MacKay	22	0	0	0	0	132	1.96	0.02	68.59	0.00	0.00	0.00
MacKay	22	0	0	1	1	132	1.96	1.35	68.59	91.59	12.97	0.38
MacKay	22	0	0	1	2	132	1.96	1.75	68.59	102.33	27.34	0.42
MacKay	22	0	0	2	1	132	1.96	2.18	68.59	99.21	19.73	0.27
MacKay	22	0	0	2	2	132	1.96	2.43	68.59	106.41	29.36	0.23
MacKay	22	0	0	3	1	132	1.96	2.67	68.59	102.13	20.42	0.30
MacKay	22	0	0	3	2	132	1.96	2.97	68.59	106.80	45.52	0.23
MacKay	22	0	0	4	1	132	1.96	3.20	68.59	93.72	26.38	0.27
MacKay	22	0	0	4	2	132	1.96	3.47	68.59	107.04	149.04	0.38
MacKay	22	0	0	5	2	132	1.96	3.70	68.59	0.00	26.67	0.00
Mahon USA	23	1	0	0	0	82	1.81	0.02	69.04	0.00	0.00	0.00
Mahon USA	23	1	0	1	1	82	1.81	1.48	69.04	112.31	4.60	0.30
Mahon USA	23	1	0	1	2	82	1.81	1.78	69.04	122.42	24.91	0.37
Mahon USA	23	1	0	2	1	82	1.81	2.15	69.04	121.86	6.08	0.27
Mahon USA	23	1	0	2	2	82	1.81	2.42	69.04	113.16	30.97	0.27
Mahon USA	23	1	0	3	1	82	1.81	2.68	69.04	112.85	17.15	0.27

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Mahon USA	23	1	0	3	2	82	1.81	2.95	69.04	128.19	18.91	0.22
Mahon USA	23	1	0	4	1	82	1.81	3.15	69.04	113.39	8.51	0.27
Mahon USA	23	1	0	4	2	82	1.81	3.43	69.04	125.96	119.96	0.18
Mahon USA	23	1	0	5	2	82	1.81	3.62	69.04	0.00	19.14	0.00
McEwen	24	0	0	0	0	116	1.91	0.02	72.96	0.00	0.00	0.00
McEwen	24	0	0	1	1	116	1.91	1.35	72.96	104.97	8.85	0.35
McEwen	24	0	0	1	2	116	1.91	1.70	72.96	117.82	29.85	0.35
McEwen	24	0	0	2	1	116	1.91	2.05	72.96	99.90	5.84	0.28
McEwen	24	0	0	2	2	116	1.91	2.33	72.96	109.49	31.49	0.27
McEwen	24	0	0	3	1	116	1.91	2.60	72.96	105.33	7.45	0.27
McEwen	24	0	0	3	2	116	1.91	2.87	72.96	104.56	25.75	0.20
McEwen	24	0	0	4	1	116	1.91	3.07	72.96	114.41	18.87	0.27
McEwen	24	0	0	4	2	116	1.91	3.33	72.96	106.71	129.35	0.25
McEwen	24	0	0	5	2	116	1.91	3.58	72.96		15.36	0.00
McGrath	25	0	0	0	0	105	1.81	0.02	71.98	0.00	0.00	0.00
McGrath	25	0	0	1	1	105	1.81	1.35	71.98	97.34	8.84	0.30
McGrath	25	0	0	1	2	105	1.81	1.67	71.98	107.96	32.43	0.28
McGrath	25	0	0	2	1	105	1.81	1.95	71.98	103.39	4.05	0.23
McGrath	25	0	0	2	2	105	1.81	2.18	71.98	96.59	26.10	0.23
McGrath	25	0	0	3	1	105	1.81	2.42	71.98	133.32	7.63	0.25
McGrath	25	0	0	3	2	105	1.81	2.67	71.98	88.84	39.23	0.22
McGrath	25	0	0	4	1	105	1.81	2.88	71.98	111.33	59.16	0.23
McGrath	25	0	0	4	2	105	1.81	3.12	71.98	101.27	50.51	0.28
McGrath	25	0	0	5	2	105	1.81	3.38	71.98	0.00	4.63	0.00
Moton	26	1	0	0	0	98	1.85	0.02	64.02	0.00	0.00	0.00

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Moton	26	1	0	1	1	98	1.85	1.43	64.02	89.99	7.22	0.42
Moton	26	1	0	1	2	98	1.85	1.85	64.02	103.30	21.23	0.35
Moton	26	1	0	2	1	98	1.85	2.23	64.02	88.08	4.14	0.43
Moton	26	1	0	2	2	98	1.85	2.63	64.02	115.61	32.66	0.23
Moton	26	1	0	3	1	98	1.85	2.88	64.02	84.79	11.54	0.32
Moton	26	1	0	3	2	98	1.85	3.17	64.02	112.47	24.22	0.20
Moton	26	1	0	4	1	98	1.85	3.38	64.02	85.85	0.40	0.25
Moton	26	1	0	4	2	98	1.85	3.65	64.02	111.40	101.19	0.25
Moton	26	1	0	5	2	98	1.85	3.87	64.02		26.31	0.00
Nutter	27	0	0	0	0	109	1.78	0.02	69.54	0.00	0.00	0.00
Nutter	27	0	0	1	1	109	1.78	1.40	69.54	81.65	10.45	0.33
Nutter	27	0	0	1	2	109	1.78	1.75	69.54	87.61	19.34	0.33
Nutter	27	0	0	2	1	109	1.78	2.08	69.54	71.53	2.50	0.23
Nutter	27	0	0	2	2	109	1.78	2.32	69.54	71.45	21.32	0.27
Nutter	27	0	0	3	1	109	1.78	2.58	69.54	69.02	14.92	0.23
Nutter	27	0	0	3	2	109	1.78	2.82	69.54	65.60	13.48	0.25
Nutter	27	0	0	4	1	109	1.78	3.05	69.54	75.57	139.03	0.22
Nutter	27	0	0	4	2	109	1.78	3.27	69.54	62.49	1.02	0.23
Nutter	27	0	0	5	2	109	1.78	3.53	69.54	0.00	29.30	0.00
Parker	28	0	0	0	0	114	1.82	0.02	73.04	0.00	0.00	0.00
Parker	28	0	0	1	1	114	1.82	1.60	73.04	106.13	15.25	0.32
Parker	28	0	0	1	2	114	1.82	1.93	73.04	94.20	32.14	0.35
Parker	28	0	0	2	1	114	1.82	2.32	73.04	102.40	7.46	0.27
Parker	28	0	0	2	2	114	1.82	2.58	73.04	95.57	42.89	0.25
Parker	28	0	0	3	1	114	1.82	2.85	73.04	88.56	10.83	0.28

Athlete	Subject	Sex	Country	Turn	Stance	Mass	Hgt	Time	Distance	ShdrtoHam	ShdrtoHips	Phasetime
Parker	28	0	0	3	2	114	1.82	3.08	73.04	93.96	25.82	0.18
Parker	28	0	0	4	1	114	1.82	3.32	73.04	103.96	12.19	0.28
Parker	28	0	0	4	2	114	1.82	3.58	73.04	92.82	35.58	0.25
Parker	28	0	0	5	2	114	1.82	3.82	73.04	0.00	8.06	0.00
Price	29	1	0	0	0	84	1.7	0.02	70.34	0.00	0.00	0.00
Price	29	1	0	1	1	84	1.7	1.32	70.34	101.75	3.08	0.32
Price	29	1	0	1	2	84	1.7	1.63	70.34	93.67	21.62	0.33
Price	29	1	0	2	1	84	1.7	1.97	70.34	99.98	7.26	0.25
Price	29	1	0	2	2	84	1.7	2.22	70.34	92.10	30.13	0.23
Price	29	1	0	3	1	84	1.7	2.45	70.34	102.82	16.12	0.25
Price	29	1	0	3	2	84	1.7	2.70	70.34	97.99	19.29	0.20
Price	29	1	0	4	1	84	1.7	2.90	70.34	107.14	13.70	0.25
Price	29	1	0	4	2	84	1.7	3.15	70.34	100.71	164.74	0.23
Price	29	1	0	5	2	84	1.7	3.35	70.34	0.00	15.29	0.00

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Annus	1	0	1	0	0	1.57	0.00
Annus	1	0	1	1	1	2.56	7648.10
Annus	1	0	1	1	2	1.30	9327.24
Annus	1	0	1	2	1	1.96	15264.27
Annus	1	0	1	2	2	1.12	17267.23
Annus	1	0	1	3	1	2.10	17458.01
Annus	1	0	1	3	2	1.52	17831.83
Annus	1	0	1	4	1	2.19	21819.89
Annus	1	0	1	4	2	1.61	19617.89
Annus	1	0	1	5	2	2.20	28817.72
Keil	2	1	1	0	0	1.42	0.00
Keil	2	1	1	1	1	1.65	5953.83
Keil	2	1	1	1	2	1.38	6193.04
Keil	2	1	1	2	1	1.59	9466.87
Keil	2	1	1	2	2	1.30	8881.86
Keil	2	1	1	3	1	1.76	11416.36
Keil	2	1	1	3	2	1.34	10598.57
Keil	2	1	1	4	1	1.54	13753.57
Keil	2	1	1	4	2	1.51	11280.27
Keil	2	1	1	5	2	6.80	4144.71
Kobs	3	0	1	0	0	3.60	0.00
Kobs	3	0	1	1	1	1.70	5317.10
Kobs	3	0	1	1	2	1.92	5049.09
Kobs	3	0	1	2	1	1.80	9854.26
Kobs	3	0	1	2	2	1.49	10705.15

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Kobs	3	0	1	3	2	1.40	14680.34
Kobs	3	0	1	4	1	1.61	21638.26
Kobs	3	0	1	4	2	1.60	18047.35
Kobs	3	0	1	5	2	5.59	9412.83
Konovalov	4	0	1	0	0	4.43	0.00
Konovalov	4	0	1	1	1	2.09	3925.72
Konovalov	4	0	1	1	2	1.65	4725.43
Konovalov	4	0	1	2	1	2.29	8762.54
Konovalov	4	0	1	2	2	1.67	10263.81
Konovalov	4	0	1	3	1	2.06	15719.70
Konovalov	4	0	1	3	2	1.74	15481.07
Konovalov	4	0	1	4	1	1.90	20446.69
Konovalov	4	0	1	4	2	1.60	21389.52
Konovalov	4	0	1	5	2	5.24	10036.76
Kozmus	5	0	1	0	0	1.29	0.00
Kozmus	5	0	1	1	1	1.99	7836.06
Kozmus	5	0	1	1	2	1.56	8889.56
Kozmus	5	0	1	2	1	2.22	12351.51
Kozmus	5	0	1	2	2	1.96	10601.17
Kozmus	5	0	1	3	1	2.35	15937.50
Kozmus	5	0	1	3	2	1.70	13998.10
Kozmus	5	0	1	4	1	2.36	18178.36
Kozmus	5	0	1	4	2	1.56	15765.09
Kozmus	5	0	1	5	2	0.00	0.00
Kuzenkova	6	1	1	0	0	3.18	0.00

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Kuzenkova	6	1	1	1	2	1.62	4646.75
Kuzenkova	6	1	1	2	1	1.75	7579.80
Kuzenkova	6	1	1	2	2	1.46	7323.91
Kuzenkova	6	1	1	3	1	1.83	10260.24
Kuzenkova	6	1	1	3	2	1.41	9782.91
Kuzenkova	6	1	1	4	1	1.77	12410.33
Kuzenkova	6	1	1	4	2	1.46	11634.67
Kuzenkova	6	1	1	5	2	5.74	5469.12
Charfreitag	7	0	1	0	0	4.11	0.00
Charfreitag	7	0	1	1	1	1.92	7497.72
Charfreitag	7	0	1	1	2	1.68	7206.89
Charfreitag	7	0	1	2	1	2.12	11285.35
Charfreitag	7	0	1	2	2	1.66	11835.31
Charfreitag	7	0	1	3	1	2.02	16721.61
Charfreitag	7	0	1	3	2	1.75	16126.09
Charfreitag	7	0	1	4	1	2.05	21714.05
Charfreitag	7	0	1	4	2	1.83	18596.55
Charfreitag	7	0	1	5	2	8.61	6154.77
Mahon WAC	8	1	1	0	0	3.13	0.00
Mahon WAC	8	1	1	1	1	1.76	5152.87
Mahon WAC	8	1	1	1	2	1.72	5135.82
Mahon WAC	8	1	1	2	1	1.96	7748.41
Mahon WAC	8	1	1	2	2	1.79	7727.23
Mahon WAC	8	1	1	3	1	1.95	11094.52
Mahon WAC	8	1	1	3	2	1.67	10991.66

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Mahon WAC	8	1	1	4	2	1.63	13425.20
Mahon WAC	8	1	1	5	2	8.83	3844.18
Melinte	9	1	1	0	0	3.07	0.00
Melinte	9	1	1	1	1	1.84	6590.01
Melinte	9	1	1	1	2	1.38	8225.07
Melinte	9	1	1	2	1	1.72	10810.17
Melinte	9	1	1	2	2	1.37	10996.84
Melinte	9	1	1	3	1	1.73	12715.40
Melinte	9	1	1	3	2	1.62	11862.87
Melinte	9	1	1	4	1	1.70	13710.92
Melinte	9	1	1	4	2	1.64	12480.40
Melinte	9	1	1	5	2	6.67	4889.41
Montebrun	10	1	1	0	0	2.20	0.00
Montebrun	10	1	1	1	1	1.98	7468.33
Montebrun	10	1	1	1	2	1.82	6580.08
Montebrun	10	1	1	2	1	1.87	11940.61
Montebrun	10	1	1	2	2	1.85	12410.26
Montebrun	10	1	1	3	1	1.92	15015.83
Montebrun	10	1	1	3	2	1.70	14808.97
Montebrun	10	1	1	4	1	1.92	17313.77
Montebrun	10	1	1	4	2	1.57	16114.43
Montebrun	10	1	1	5	2	9.59	3991.21
Moreno	11	1	1	0	0	2.90	0.00
Moreno	11	1	1	1	1	1.79	4220.53
Moreno	11	1	1	1	2	1.58	5122.15

Athlete	**Subject**	**Sex**	**Country**	**Turn**	**Stance**	**Radius**	**Centripal Force**
Moreno	11	1	1	2	2	1.25	8445.38
Moreno	11	1	1	3	1	1.71	11237.11
Moreno	11	1	1	3	2	1.47	11487.27
Moreno	11	1	1	4	1	1.75	13012.93
Moreno	11	1	1	4	2	1.32	13956.60
Moreno	11	1	1	5	2	3.53	8797.98
Murofushi	12	0	1	0	0	2.49	0.00
Murofushi	12	0	1	1	1	1.14	8712.24
Murofushi	12	0	1	1	2	0.91	11291.10
Murofushi	12	0	1	2	1	1.15	14051.51
Murofushi	12	0	1	2	2	1.01	13976.55
Murofushi	12	0	1	3	1	1.47	17722.87
Murofushi	12	0	1	3	2	1.32	14934.38
Murofushi	12	0	1	4	1	1.66	19146.68
Murofushi	12	0	1	4	2	1.66	15810.95
Murofushi	12	0	1	5	2	5.70	7859.21
Sekochova	13	1	1	0	0	3.80	0.00
Sekochova	13	1	1	1	1	1.68	4440.55
Sekochova	13	1	1	1	2	1.33	5035.15
Sekochova	13	1	1	2	1	1.74	7916.34
Sekochova	13	1	1	2	2	1.31	8653.57
Sekochova	13	1	1	3	1	1.53	11392.90
Sekochova	13	1	1	3	2	1.27	10635.32
Sekochova	13	1	1	4	1	1.62	12746.46
Sekochova	13	1	1	4	2	1.28	11862.49

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Skolimowska	14	1	1	0	0	2.55	0.00
Skolimowska	14	1	1	1	1	1.94	8281.95
Skolimowska	14	1	1	1	2	1.43	9538.92
Skolimowska	14	1	1	2	1	1.80	13986.15
Skolimowska	14	1	1	2	2	1.46	13032.76
Skolimowska	14	1	1	3	1	1.61	17437.84
Skolimowska	14	1	1	3	2	1.48	14704.14
Skolimowska	14	1	1	5	2	4.62	7846.24
Skvaruk	15	0	1	0	0	2.35	0.00
Skvaruk	15	0	1	1	1	2.13	3353.39
Skvaruk	15	0	1	1	2	1.67	4286.69
Skvaruk	15	0	1	2	1	2.17	8253.42
Skvaruk	15	0	1	2	2	1.54	9908.58
Skvaruk	15	0	1	3	1	1.86	13094.64
Skvaruk	15	0	1	3	2	1.64	13729.83
Skvaruk	15	0	1	4	1	1.89	15975.99
Skvaruk	15	0	1	4	2	1.46	16236.22
Skvaruk	15	0	1	5	2	0.08	499891.50
Tikhon	16	0	1	0	0	3.61	0.00
Tikhon	16	0	1	1	1	1.91	8648.35
Tikhon	16	0	1	1	2	1.49	9634.96
Tikhon	16	0	1	2	1	2.10	13760.16
Tikhon	16	0	1	2	2	1.59	13883.43
Tikhon	16	0	1	3	1	1.99	17269.22
Tikhon	16	0	1	3	2	1.57	16781.04

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Tikhon	16	0	1	4	2	1.60	17736.56
Tikhon	16	0	1	5	2	4.42	12238.61
Ellerbe	17	1	0	0	0	1.67	0.00
Ellerbe	17	1	0	1	1	1.72	8275.50
Ellerbe	17	1	0	1	2	1.54	10711.69
Ellerbe	17	1	0	2	1	1.63	10890.83
Ellerbe	17	1	0	2	2	1.20	15201.28
Ellerbe	17	1	0	3	1	1.59	15355.43
Ellerbe	17	1	0	3	2	1.47	15306.30
Ellerbe	17	1	0	5	2	3.46	10727.45
Campbell	18	1	0	0	0	1.76	0.00
Campbell	18	1	0	1	1	1.75	7303.10
Campbell	18	1	0	1	2	1.41	8051.33
Campbell	18	1	0	2	1	2.06	9430.50
Campbell	18	1	0	2	2	1.69	9017.35
Campbell	18	1	0	3	1	2.01	12694.55
Campbell	18	1	0	3	2	1.66	11922.38
Campbell	18	1	0	4	1	2.18	10436.29
Campbell	18	1	0	4	2	1.84	10958.80
Campbell	18	1	0	5	2	7.30	4893.53
Dickerson	19	1	0	0	0	2.37	0.00
Dickerson	19	1	0	1	1	2.55	8080.69
Dickerson	19	1	0	1	2	3.11	6232.44
Dickerson	19	1	0	2	1	3.56	8118.72
Dickerson	19	1	0	2	2	2.50	9040.63

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
Dickerson	19	1	0	3	2	2.74	12084.76
Dickerson	19	1	0	4	1	2.33	12450.06
Dickerson	19	1	0	4	2	2.09	17222.46
Dickerson	19	1	0	5	2	7.86	4958.08
Freeman	20	0	0	0	0	2.02	0.00
Freeman	20	0	0	1	1	2.09	17024.09
Freeman	20	0	0	1	2	1.66	18770.68
Freeman	20	0	0	2	1	2.29	25653.66
Freeman	20	0	0	2	2	1.59	28261.37
Freeman	20	0	0	3	1	2.22	33390.50
Freeman	20	0	0	3	2	1.83	30623.78
Freeman	20	0	0	4	1	2.43	29920.64
Freeman	20	0	0	4	2	2.33	30088.34
Freeman	20	0	0	5	2	9.39	13259.75
Gilreath	21	1	0	0	0	0.24	0.00
Gilreath	21	1	0	1	1	0.89	6987.41
Gilreath	21	1	0	1	2	0.18	51695.55
Gilreath	21	1	0	2	1	1.26	9919.22
Gilreath	21	1	0	2	2	0.84	18854.68
Gilreath	21	1	0	3	1	1.47	5827.28
Gilreath	21	1	0	3	2	1.53	12340.67
Gilreath	21	1	0	4	1	1.69	14013.97
Gilreath	21	1	0	4	2	1.25	20853.75
Gilreath	21	1	0	5	2	9.15	3535.36
MacKay	22	0	0	0	0	1.88	0.00

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
MacKay	22	0	0	1	2	1.75	18848.58
MacKay	22	0	0	2	1	1.69	32523.79
MacKay	22	0	0	2	2	1.78	28524.52
MacKay	22	0	0	3	1	2.15	33381.55
MacKay	22	0	0	3	2	1.73	34641.41
MacKay	22	0	0	4	1	2.13	40089.64
MacKay	22	0	0	4	2	1.81	35457.55
MacKay	22	0	0	5	2	0.00	0.00
Mahon USA	23	1	0	0	0	1.08	0.00
Mahon USA	23	1	0	1	1	1.46	4587.99
Mahon USA	23	1	0	1	2	0.88	6875.74
Mahon USA	23	1	0	2	1	1.62	6213.42
Mahon USA	23	1	0	2	2	1.04	8863.97
Mahon USA	23	1	0	3	1	1.60	8712.95
Mahon USA	23	1	0	3	2	1.40	10656.87
Mahon USA	23	1	0	4	1	1.63	10843.98
Mahon USA	23	1	0	4	2	1.86	11357.30
Mahon USA	23	1	0	5	2	0.07	371636.10
McEwen	24	0	0	0	0	1.76	0.00
McEwen	24	0	0	1	1	1.96	17900.94
McEwen	24	0	0	1	2	1.65	17986.61
McEwen	24	0	0	2	1	1.97	21927.48
McEwen	24	0	0	2	2	1.87	25740.21
McEwen	24	0	0	3	1	2.17	30328.74
McEwen	24	0	0	3	2	1.85	32264.89

Athlete	Subject	Sex	Country	Turn	Stance	Radius	Centripal Force
McEwen	24	0	0	4	2	1.88	36855.75
McEwen	24	0	0	5	2	13.12	8059.76
McGrath	25	0	0	0	0	1.71	0.00
McGrath	25	0	0	1	1	1.81	16221.85
McGrath	25	0	0	1	2	1.66	17906.76
McGrath	25	0	0	2	1	1.60	25887.81
McGrath	25	0	0	2	2	1.48	29509.48
McGrath	25	0	0	3	1	1.48	34537.84
McGrath	25	0	0	3	2	1.38	36792.68
McGrath	25	0	0	4	1	1.41	41833.47
McGrath	25	0	0	4	2	1.40	39111.38
McGrath	25	0	0	5	2	1.66	32629.11
Moton	26	1	0	0	0	1.62	0.00
Moton	26	1	0	1	1	1.75	4887.71
Moton	26	1	0	1	2	1.63	4886.39
Moton	26	1	0	2	1	1.77	8218.77
Moton	26	1	0	2	2	1.57	10324.73
Moton	26	1	0	3	1	1.61	10933.71
Moton	26	1	0	3	2	1.54	11691.65
Moton	26	1	0	4	1	1.55	14564.75
Moton	26	1	0	4	2	1.45	14986.50
Moton	26	1	0	5	2	7.17	4847.47
Nutter	27	0	0	0	0	1.71	0.00
Nutter	27	0	0	1	1	1.72	19551.84
Nutter	27	0	0	1	2	1.64	21872.80

Nutter	27	0	0	2	2	1.55	32477.19
Nutter	27	0	0	3	1	1.43	32464.42
Nutter	27	0	0	3	2	1.92	33652.93
Nutter	27	0	0	4	1	1.46	33834.69
Nutter	27	0	0	4	2	4.56	19296.47
Nutter	27	0	0	5	2	10.48	8094.82
Parker	28	0	0	0	0	1.61	0.00
Parker	28	0	0	1	1	1.44	13968.49
Parker	28	0	0	1	2	1.64	14601.27
Parker	28	0	0	2	1	1.55	23058.79
Parker	28	0	0	2	2	1.60	23923.18
Parker	28	0	0	3	1	1.48	32299.25
Parker	28	0	0	3	2	1.41	32534.99
Parker	28	0	0	4	1	1.70	32741.70
Parker	28	0	0	4	2	1.30	39302.08
Parker	28	0	0	5	2	1.94	31814.66
Price	29	1	0	0	0	1.38	0.00
Price	29	1	0	1	1	1.72	5245.46
Price	29	1	0	1	2	1.55	6238.40
Price	29	1	0	2	1	1.75	9147.24
Price	29	1	0	2	2	1.42	9561.00
Price	29	1	0	3	1	1.94	11215.90
Price	29	1	0	3	2	1.51	12010.55
Price	29	1	0	4	1	1.94	13030.43
Price	29	1	0	4	2	1.62	12775.47
Price	29	1	0	5	2	6.17	5920.88