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Lower Body Kinetics During the Delivery Phase of the Rotational Shot Put Technique

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ABSTRACT

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The purpose of this study was to measure the change in joint energy of the hip, knee and ankle of the right and left leg, in the sagittal plane during the delivery phase of the rotational shot put. We hypothesized that (1) throwers who produced a greater total hip energy change would have greater horizontal displacement and (2) throwers who produced a higher ratio of hip energy, in each leg independently, would produce greater horizontal displacement. Subjects (n = 8) must have been right-handed, collegiate or post collegiate level throwers trained in the rotational technique. Vicon Nexus System (Denver, CO, USA) used six MX13+, two F20, two T20 cameras recorded at 240 Hz, and the body Plug-in Gait model to track the body position during each trial. Two AMTI force plates (OR-6, Watertown, MA, USA) were used for collecting ground reaction force data at 960 Hz. A linear regression analysis was performed to determine a relationship between total hip energy change and horizontal displacement. A mixed model regression was used to determine any correlation between horizontal distance and left and right energy change ratios. Athletes who produced a greater total hip energy change had the greatest horizontal displacement ($p = .022$). Also throwers who produced a higher ratio of left hip energy change to total left leg energy produced the greatest horizontal displacement ($p = .02$). The ratio of right hip energy change to right leg energy change was found to not be significant to horizontal displacement ($p = .955$). We feel the findings on the left leg energy change are an attempt by the athlete to both accelerate the shot put as well as stop the rotational progression to allow the athlete to complete a fair throw. The athlete extending both the right and the left hip rapidly during the delivery phase can help explain the combined right and left hip energy change. This action accelerates the ball in a proximal-distal sequence, which allows athletes to reach high final shot put velocities. The higher the final velocity on the shot put positively correlates with the horizontal displacement.

Key Words: shot put, joint moments, force profile, energy.

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Introduction

The shot put has been an Olympic event since 1896, and since then, the sport has seen many changes from equipment to technique. To compete at the highest level, shot putting requires an athlete to be strong, powerful, and quick. The energy output of the legs is one of the most important factors in determining the distance achieved, but little is known about the actual forces being produced during the delivery phase of the shot put (Coh, Stuhec, & Supej, 2008; McCoy, Gregor, Whiting, & Rich, 1984).

Kinematic research has shown that release velocity and release angle is inversely related (Bartonietz, 1994a; Coh et al., 2008; Young, 2004). The other critical factor, release height is determined mostly by the height of the athlete. The previous studies have focused on these release parameters of the shot put because they are relatively easy to measure. Collection of force and power data is difficult because the shot put can be dangerous in most laboratory settings where force plates and motion tracking cameras are available.

There is little data on force and change in joint energy during the delivery phase of the shot put. One study found that the energy demands on the left leg can be three times higher than the right leg (Bartonietz, 1994b). The demands on the left leg could be higher because the left leg is both stopping the rotational delivery of the shot put as well as lifting the shot put as the athlete gets fully extended and eventually comes off the ground, thus maximizing their release height. McCoy et al. (1984) concluded that 95-percent of the final velocity of the shot put at release is created by the left leg extension and right leg extending and rotating creating a "corkscrew" effect during the delivery phase. Many coaches and throwers have always believed accelerating hip extension is important, however, this idea has not yet been objectively supported via scientific means.

The lower body, during the delivery phase of the shot put, is doing work to accelerate the shot put, work being defined as force acting through a distance. Work is a change in energy, and for the purpose of this study we wanted to measure the change in joint energy of the hip, knee and ankle of the right and left leg in the sagittal plane during the delivery phase of the shot put. For the purpose of this study, the delivery phase will be defined as the time between touch down of the right foot in the middle of the ring until the last foot leaves the ground. In right-handed throwers, the last foot is often the right, but can occasionally be the left foot. We hypothesized that throwers who produced a greater total lower body energy change will have greater horizontal displacement. We also hypothesized that throwers who produced a higher ratio of hip energy change, in each leg independently, would produce greater horizontal displacement.

Methods

Subjects

Eight subjects who were male collegiate or post collegiate throwers (age 23 ± 4 years; body mass 123 ±14 kg; height 190 ± 4 cm) participated in this study (Table 2). All subjects were right handed and trained in the rotational technique of the shot put. Approval for this study was obtained from the University's institutional review board prior to data collection.

Data Collection

After arriving to the lab, each athlete signed an approved consent form. They self reported their height and weight. They were then instructed to warm-up in their own specific manner. They were then allowed to take practice throws in the lab ring to become familiar with the environment.

Upper and lower body segment parameters were measured, and results were entered into the Vicon Nexus (Denvery, CO, USA). Body parameters measured are listed under Figure 2, which shows the placement of the 36 reflective markers. Vicon Nexus System used six MX13+, two F20 and two T20 cameras recorded at 240 Hz and the body Plug-in Gait model to track the body position during the throwing trials. Two AMTI force plates (OR-6, Watertown, MA, USA) were used for collecting ground reaction force data at 960 Hz (Figure 2). To determine horizontal distance, two Casio FH100 cameras (120 Hz), with survey pole calibration, were positioned 45-degrees from each other; these cameras were used to measure speed, angle and height of release of the shot after it left the subject's hand. Athletes were asked to complete at least 3 fair trials with a maximum amount of 30 throws allowed. Each trial was visually monitored to make sure the subjects hit the force plates correctly, with one only one foot on a force plate, and no part of their foot touching the outside on the wooden ring. If the subjects did not hit the force plate in that manner they were asked to complete another attempt. No athlete exceeded 30 trials. Athletes dictated their own rest period, which for most athletes was 30-60 seconds.

Data Analysis

Vicon Nexus was used to calculate internal net joint moments in the sagittal plane at the hip, knee, and ankle of each leg, normalized by weight. A 6 Hz Butterworth filter was used on the position data. Net joint moments were calculated during the delivery phase, as was previously defined. Joint power was calculated about the hip, knee, and ankle, as the product of joint angular velocity and joint moment. Mechanical work, or the change in mechanical energy, about each joint was determined to be the integral of joint power curve during the delivery phase. Total change in joint energy for each leg was calculated as the sum of joint work during the delivery phase. Ratios of work performed at the hip and total work were calculated for each leg.

In order to determine horizontal distance that the shot put would have traveled, Vicon Motus was used to digitize the shot put for eight frames prior to and following release. Release velocity, angle, and height were determined and used to calculate horizontal displacement.

Statistical Analysis

Data for each thrower was averaged then analyzed using SPSS 18. Related to our first research question, a linear regression analysis was performed; the relationships between total lower-body energy change and horizontal distance. Related to our second research question, a mixed model regression was used. The mixed model determined whether any correlation existed between horizontal distance and left and right hip energy changes to total energy changes in each leg.

Results

Mean and standard deviations of horizontal displacement of the shot was 16.05 m ± 2.12 m. Total lower body energy change during the delivery phase was correlated with throwing distance with a slope of 4.41 J/m (F = 12.95, *p* = .011, r = .683). The ratio of left hip energy change to left leg energy change was also found to be significant with a slope of 4.246 J/m (F = 9.993, *p* = .020, r = .625). The ratio of right hip energy change to right leg energy change was not found to be significant (F = .003, *p* = .955).

Discussion

The primary purpose of this study was to examine the relationship between lower extremity joint energy change and performance for trained male rotational shot putters. Previous researchers focused on the kinematic factors of the shot put. Few studies have measured kinetics of the rotational shot put, and this is the first study to measure the change in joint energy during the delivery phase of the shot put. Our original hypotheses were: (1) throwers who produced a greater total lower-body energy change will have greater horizontal displacement and (2) that throwers who have a higher ratio of hip energy change in each leg independently will produce greater horizontal displacement. Related to our first hypothesis, we found that throwers who had a greater lower-body energy change, had a further horizontal displacement. Related to our second hypothesis, only the ratio of left hip energy change to left leg energy change was found to be significant. The right hip, while still important for the total energy change, was not found to be significant to distance when compared with the right leg energy change.

For rotational throwers, this means that the more an athlete is able to increase the amount of energy through the lower body during the delivery phase of the shot put, the further their shot put will travel. These findings also indicate the importance of the change in energy of the left hip ratio. Coaches refer to the left leg as the block or stop leg (An, Kaufman, & Chao, 1989; Bartonietz, 1994a; Smith, 2005; Young & Li, 2005). In the rotational shot put, the block leg is very important to help increase energy in an upward direction so the athlete will be able to stay inside the competition circle (Bartonietz, 1994b). The left hip was found in this study to be positively correlated to the horizontal distance and, therefore, as the hip rotates and extends quickly the horizontal distance will increase. With more energy available, the more energy it requires to stop the athlete's body from its rotational path. This is similar to data found on the glide technique in which the left leg did three times the amount of work than the right leg (Bartonietz, 1994b). The left hip extension helps determine the final velocity of the shot put, but also angle of release and a small portion of release height (Coh et al., 2008; Lichtenberg & Wills, 1978; Linthorne, 2001).

The correlation of these events, the acceleration of the right hip and the left hip extension, is extremely important to get maximum horizontal velocity. The movements that create final velocity on the shot must be sequential and follow the proximal-distal sequence from the legs through the core to the upper body then through the shot (Coh et al., 2008). Segmental sequencing of kinetic energy has been researched in other sports such as golf. Golfers exhibit similar patterns in their golf swing through a series of rotations beginning with their hips through their torso, arm rotations, which in turn accelerate the distal club head (Anderson, Wright, & Stefanyshyn, 2006). While this study did not investigate the sequencing of the right and left hip energy change, more research could help coaches and athletes train more effectively.

This study found the ratio of total hip energy change to total change in energy due to the lower body is an important factor during the delivery phase of the shot put mainly due to the left side. To incorporate the sequencing correctly, we must also look at the entire system including the other joints. All joints, while maybe not significant, will be involved in the linking and timing to create the maximum distance, including upper body joints. McCoy et al. (1984) found that 95-percent of the final velocity of the shot was produced during the delivery phase or the last 15-percent of the throw. The delivery phase is a vital component of final velocity of the shot put and must be studied more fully.

There were some limitations related to this study. First, while the throwing circle measured the same as a competition ring and surfaces were similar to competition rings, the laboratory environment is not going to produce exact competition level throws. Second, with the force plates being positioned generally, not specific to each athlete, some subjects had to shift their normal starting positions to hit the force plates correctly. Third, subjects that participated in the study were in a fall season of training. Often during the fall season of training athletes are in the beginning stages of refining their technique. For future reference, having a venue that is more like a competition during their proper competition season could minimize some of these limitations and increase validity.

In conclusion, we found that athletes who produce greater lower body energy changes will have greater horizontal displacement. More specifically, greater horizontal displacements are found through using a greater proportion of left hip to total left leg in this energy change. These findings show athletes the importance of the change in left hip energy during the delivery phase and will help athletes train more appropriately. Throwers should focus their lower body training on movements that focus on acceleration powerful hip extension. By focusing on these two factors, rotational shot putters will hopefully be able to improve their technique and, in turn, increase their personal bests.

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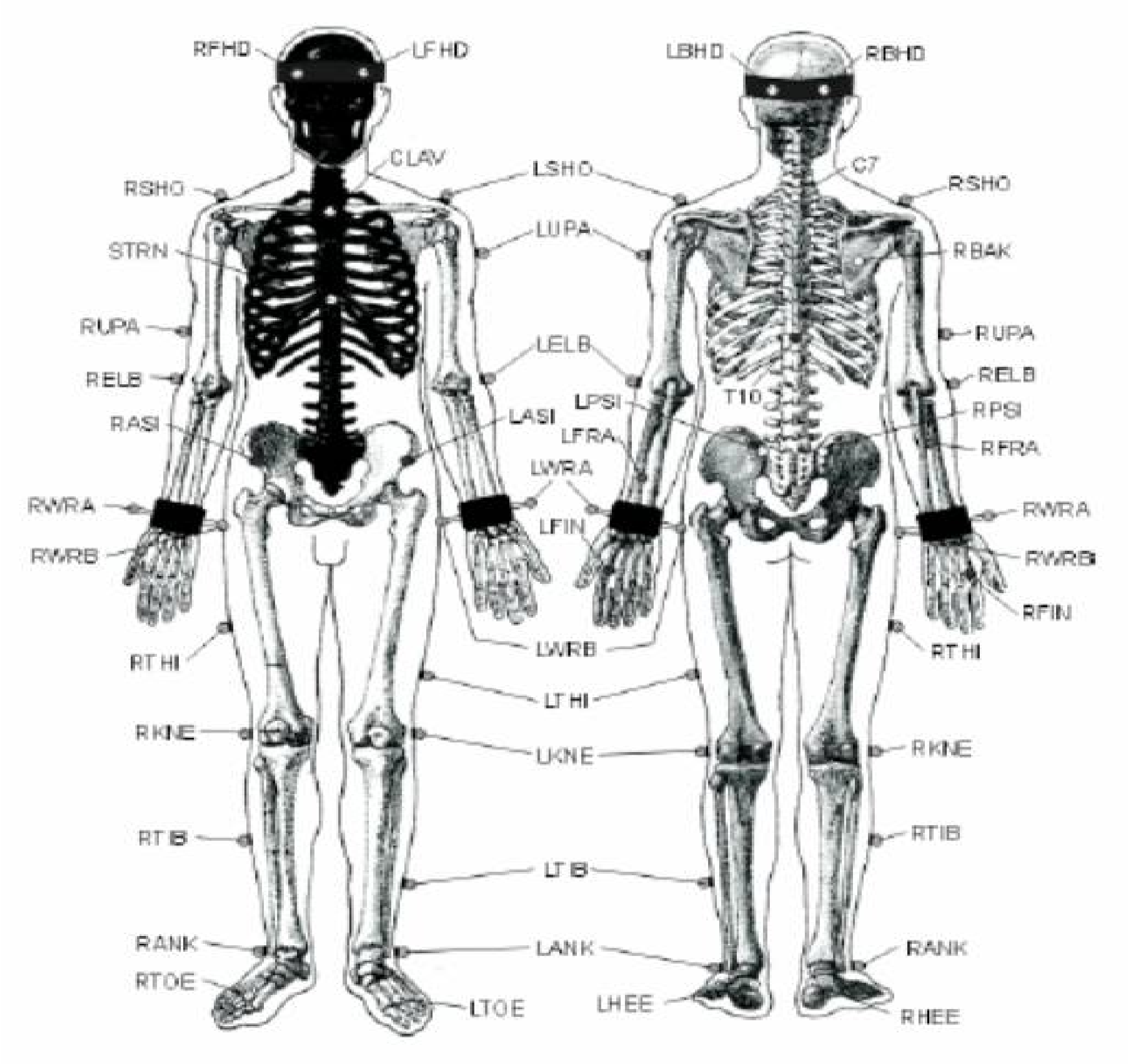
Table 1. The average distances per thrower as well as the average throw for the experiment along with standard deviations. Average ratios of both right, left and total leg energy changes for each thrower and for entire experiment.

Subject	**Average Distance Per Subject (m)**	**Ratio Left Hip to Left Leg Total Energy Change**	**Ratio Right Hip to Right Leg Total Energy Change**	**Total Lower Body Energy Change (J)**
1	16.49	0.20	0.10	2.82
2	13.43	-0.08	0.43	2.11
3	13.41	-0.06	0.30	2.59
4	14.38	1.08	0.33	3.12
5	17.74	-0.02	0.16	2.12
6	15.95	0.53	0.36	2.80
7	18.50	0.45	-0.06	3.04
8	18.47	0.20	0.35	3.01
Mean	16.05	0.29	0.25	2.70
SD	2.12	0.40	0.16	0.40

Table 2. Subject Demographics

Subject	Mass (kg)	Height (m)	Age
1	126	1.920	29
2	111	1.829	23
3	133	1.956	18
4	104	1.880	21
5	120	1.910	25
6	114	1.905	21
7	139	1.930	22
8	41	1.910	27

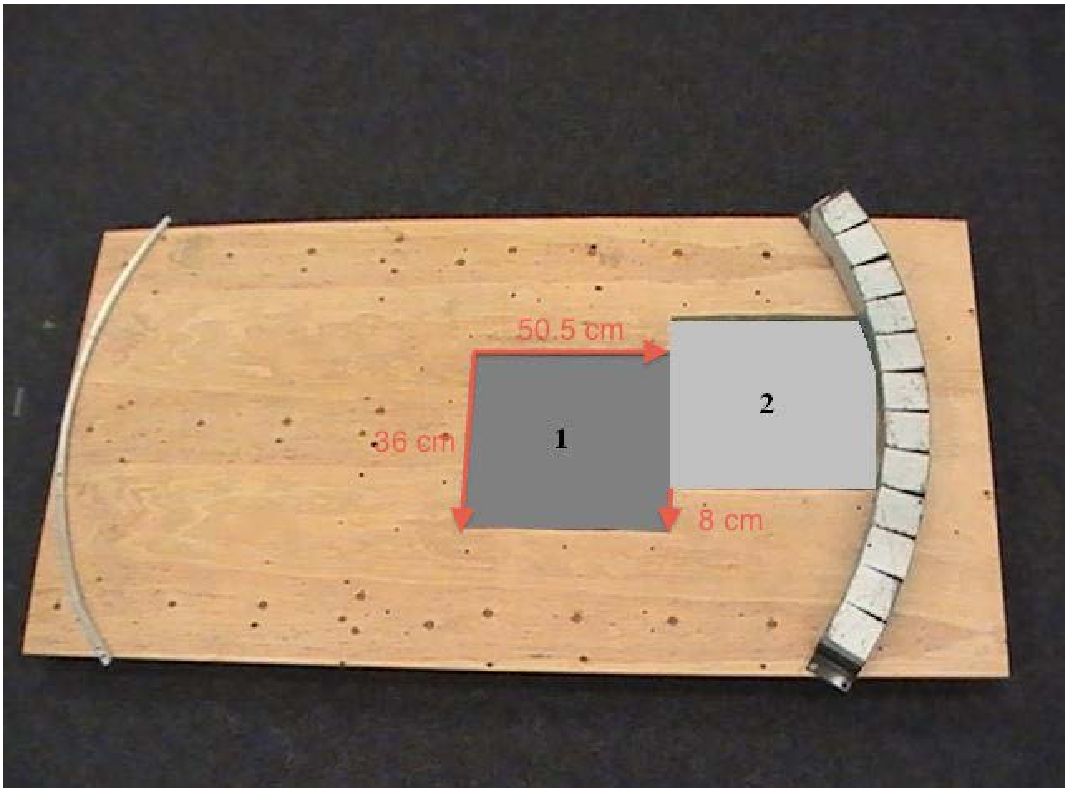
Figure 1. The placement of the 36 reflective markers used in the Vicon Gait Plug-in system.



Measured Body Segments:

Left lower leg, right lower leg, left knee width, right knee width, left ankle width, right ankle width, left shoulder width, right shoulder width, left elbow width, right elbow width, left wrist width, right wrist width, left hand width, right hand width, left ASIS, right ASIS and inter ASIS.

Figure 2. Lay out of the shot put ring and the placement of the two force plates.



Appendix A: Prospectus

Prospectus

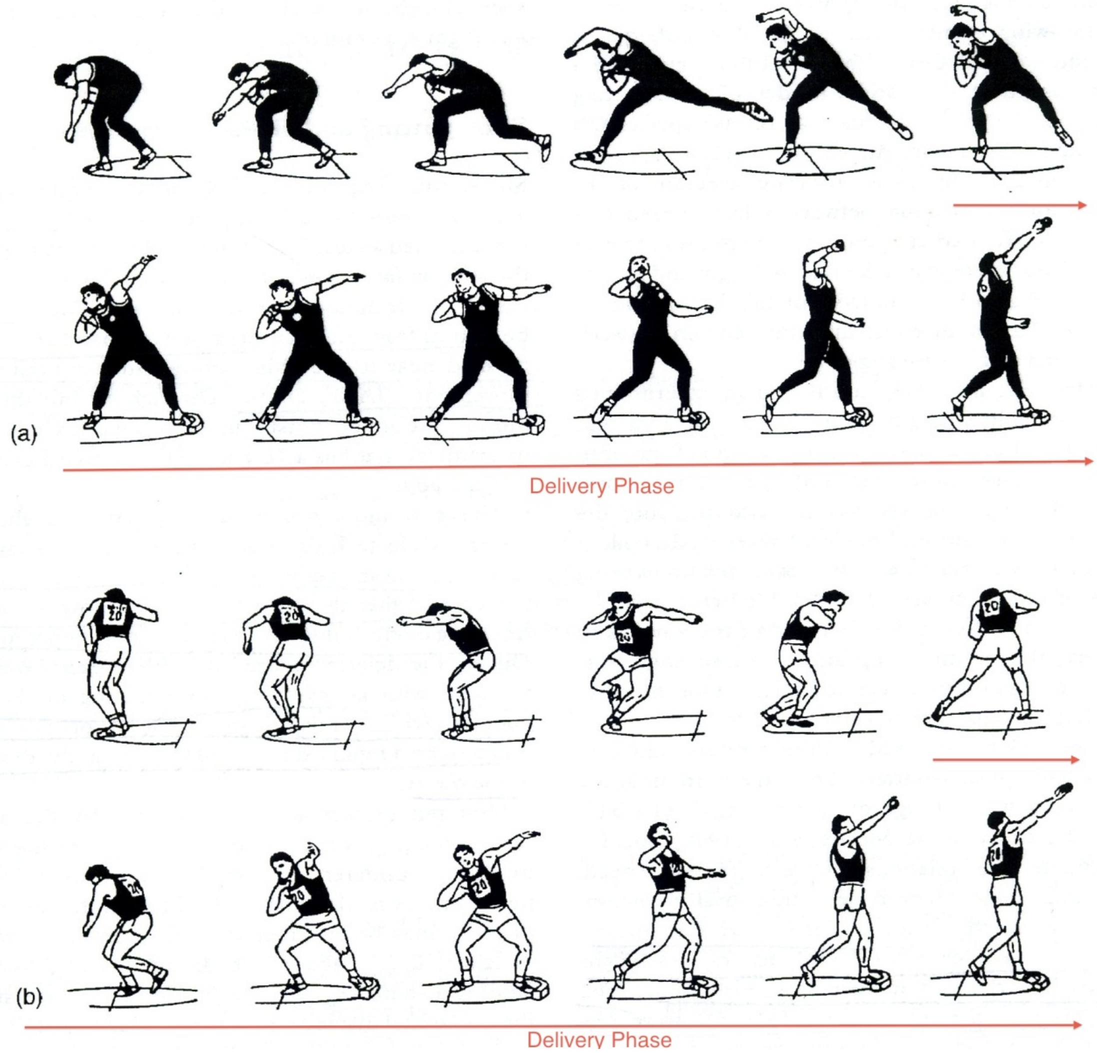
Introduction

During the first modern Olympics in 1896 in Athens, Greece, the men's shot put was contested. The winner, Robert S. Garrett of the United States of America, threw a distance of 11.22 meters, or 36 feet 8 inches ("Garrett, Robert S." n.d.). In the first women's Olympic shot put competition in 1948, Micheline Ostermeyer won the event with a throw of 13.75 meters, or 45 feet 1.5 inches ("Ostermeyer, Micheline" n.d.). Since that time, the shot put has taken leaps and bounds in distance and technique, and both genders have seen world record throws over 22.5 meters or 74 feet ("IAAF World Records" n.d.). Despite early revolutions in technique, the most noticeable difference in distance in the most recent history of the shot put is the size and strength of the competitors. For throwers, most of the power used to throw the shot comes from the push of the drive leg in the middle of the ring through the ground as the hips rotate around and the shoulders stay as close to perpendicular to the hips as possible. The ground reaction forces created from this move are a vital component for far throws (Coh, Stuhec, & Supej, 2008b).

Current studies on the shot put have revealed three key factors that determine the final distance of the throw. These three key factors are first, release height, second release angle, and third, and most important, release velocity (Hubbard, de Mestre, & Scott, 2001; Young, 2004). Release height is the least important of the three factors while release angle and release velocity have an inverse relationship with each other (Young, 2004). Release velocities greater than 13 meters per second are found to be necessary for elite level throws, while an optimal angle occurs around 31-37 degrees depending on anthropometric measurements (Young, 2004). While these three factors are considered crucial to far a throw, no studies have measured the joint moments at the hip, knee, or ankle that are critical to achieve the established critical factors in the shot put.

Kinematics has been the major focus for data collection on the shot put due to the difficulty of measuring lower body force profiles of an event such as the shot put (Bosen, 1985; Coh et al., 2008b; R. W. McCoy, R. J. Gregor, W. C. Whiting, & R. G. Rich, 1984; Young, 2004). Current studies are able to establish such criteria as critical factors, but little is known about the forces contributing to the power in the release phase in the shot put. These phases help determine the amount of height, velocity, and release angle, and, therefore, the overall distance, but current training for the shot put does not focus on these factors (Bakarinov & Oxerov, 1985). Training for most shot putters focuses on the speed-strength relationship, or forces being applied during the throw, and less on critical factors determined by recent studies (Bakarinov & Oxerov, 1985; Smith, 2005). The current study hopes to look at the measured joint moments through this important phase of the shot put to understand more fully the energy applied in the delivery to help throwers in their training.

The purpose of this study is to measure the joint moments during the delivery phase of the shot put for the rotational technique. The ultimate objective is to provide shot putters and coaches with more knowledge of the technique so they can implement proper training programs to help improve the distance of the shot and ultimately break more world records.



(Linthorne, 2001b)

Statement of the Problem

To determine the relationship between lower extremity kinetics and performance for trained male right handed rotational shot putters.

Hypothesis

1. Throwers who produce greater total energy of both the right and the left legs have greater horizontal displacement.

2. Throwers with greater proportions of energy from hip involvement during the delivery phase of the shot put with have greater horizontal displacement.

Null Hypothesis

1. Throwers with greater total energy of the right and left legs will not have greater horizontal displacement.
2. Horizontal displacement will not be greater in throwers with a greater proportion of energy from hip involvement.

Delimitations

1. Sample size
2. The use of only the rotational techniques of the shot put
3. The number of trials being used
4. Defining the trials as usable and unusable.

Limitations

1. The lab environment of the testing area may be too confined compared to real world shot put competitions and practices.
2. The different surfaces of the wooden ring and the force plate may cause a decreased effort in early attempts as the subject gets use to the testing surfaces.

Operational Definitions

Joint moments: the sum of forces through a joint created by the muscles that cross and or surround that particular joint.

Drive leg: the leg that is in the center of the ring during delivery phase that is driving and rotating against the block leg, also known as the rear foot.

Block leg: the leg that is at the front of the ring nearest the toe board that is countering the drive leg, also known as the front foot..

Rear foot and front foot: the foot furthest away from and closest to the toe board when the athlete is in double support following the flight phase.

Delivery phase: The time between rear foot touch down and the releasing of the shot put.

(Young, 2004)

Review of Literature

Over the last few decades, the shot put has gone through many changes based on an improved application of physical laws to human performance. Technique has advanced from the basic stand throw to the "shuffle step," to the now widely used glide and rotational style throws. Equipment and surface advances have come from dirt rings, and spikes, to cement and highly specialized shoes. The shot put today is dramatically different from its cannonball throwing origins. A trial and error process by individuals began to take place because they felt there was more potential in the power applied to the shot put during a throw by modifying the movement patterns. The changes seen in the shot put technique have all been attempts to improve the distance through scientific means, but these have not been in an experimental environment. Many measurements, such as ground reaction forces and joint moments, have gone untested even though they are critical to the final distance of the throw. Through video analysis, recent studies have attempted to explain the changes in technique as well as discover important movements that are critical to far throws (Coh et al., 2008b; Hubbard et al., 2001; R. W. McCoy et al., 1984; M. Young & L. Li, 2005; Young, 2004). This literature review attempts to look at the observed factors found in the shot put as well as the holes that are yet to be filled in this area of study.

Rotational Technique Explained

There are currently two widely accepted techniques being used by both non-elite and elite throwers around the world: the rotational and the glide. The technique that is being more widely used currently is the rotational technique. Understanding this technique is very important to understand the literature. One of the major differences between the glide and the rotational is the path of the ball. In the glide technique, the shot put travels across the ring in a straight line with a 180-degree turn at the finish. The path of the ball is very short compared to the rotation. The path of the shot for the rotational is much longer, traveling a total of at least 540-degrees allowing for more application of force. Whether you are a glider or a rotational thrower, the goal position at the front is the same. This position is called the power position. From the power position, the athlete drives the pivot foot around as the hips turn towards the sector, keeping the shoulders back to create shoulder-hip separation (torque). The block leg as it straightens and blocks the left side to transfer the forces generated from the trunk torque into the release as the throwing shoulder comes around to deliver the shot put (Bosen, 1985).

The rotational shot putter starts with his shoulders facing away from the sector, but both feet are at the back of the ring, splitting the center of the circle. The block leg begins as the leg that will push off the back of the circle and the drive leg begins as the sweep leg. To start the throw, the hip of the block leg turns towards the center of the ring as the drive/sweep leg pushes off and "sweeps" the outside of the ring. As the sweep leg becomes even with the drive leg, it kicks towards the center of the ring with the shoulders now facing the sector. As this occurs, the drive leg lifts off the back of the ring and the thrower is now in mid-air. The sweep leg touches down in the center of the ring and continues to pivot as the body completes a 360-degree turn. With the center of mass over the sweep leg and the shoulders back facing opposite the sector, the drive leg comes through and lands at the front near the toe board. The thrower is now in the previously mentioned power position, and the throw continues in a similar manner to put the shot. Knowing the rotational shot technique will help in reviewing the literature and will show how much research still needs to be done on forces being applied during the delivery phase of the shot (Bartonietz, 1994a, 1994b; Bosen, 1985).

Release Variables

Whether an athlete is a glider or a rotary thrower, common variables have been found in many studies that determine particular release variables to be most important in determining the distance the shot put will travel (Bartonietz, 1994a, 1994b; Hubbard et al., 2001; R. W. McCoy et al., 1984; M. Young & L. Li, 2005). Through video analysis of elite throwers, studies have found that the release velocity, height of release, and angle of release are three of the most important factors, known as critical factors, which determine the final distance of the shot put (Coh et al., 2008b; M. Young & L. Li, 2005; Young, 2004). Critical factors are the parameters in technique that are most influential for a successful performance (M. Young & L. Li, 2005; Young, 2004). The critical factors for the shot put were found to be independent of the type of technique used (M. Young & L. Li, 2005).

Release velocity is the most influential that affects the distance the shot travels. Height and angle of release, the other two critical factors, tend to be fixed based on anthropometric factors; therefore, velocity can be changed the most through proper technique and conditioning (Bartonietz, 1994a, 1994b; Bosen, 1985; Hubbard et al., 2001; R. W. McCoy et al., 1984; M. Young & L. Li, 2005). McCoy et al. (1984) found that from the power position, velocity of the shot increased dramatically until the release and, therefore approximately 95% of the final velocity was achieved in the last 15% of the throwing motion. These findings show that the positions established at the front of the circle, before the release are important in determining the distance of the throw. By studying the joint moments at the time of left foot touchdown, we can see the forces used by the body to generate the high release velocity. None of the previous studies have looked at these forces, and this study hopes to fill that void in the literature.

Genetic-Anthropometric Factors

One of the most important influences on the shot put is body type (genetic make-up). Overall longer levers of taller athletes will be advantageous over shorter counterparts (Coh et al., 2008b). While this factor tends to be true, a few of top men shot putters are 6 feet tall or less, which is short when you compare them to the many 6 foot 8-inch men that enter the 7-foot circle. In many cases, the genetic-anthropometric factors dictate the type of technique used by an athlete and, therefore, you see taller competitors using the glide technique while shorter athletes use the rotational (Bosen, 1985; Hubbard et al., 2001). (Bosen, 1985; Coh et al., 2008b; Hubbard et al., 2001; R. W. McCoy et al., 1984; M. Young & L. Li, 2005; Young, 2004)In a comparison of two rotational shot putters, Coh et al. (2008) found that the anthropometric characteristics of the shot putter largely define his technique model. One of the components of optimal release is the release height . A taller thrower increases his advantage by being able to have a much higher point of release due to his height and, by in large, his longer levers.

Along with release height is the muscle size, fiber type, and flexibility of the abdominal region to allow for maximal torque at left foot touch down. The "musculoskeletal structure" and the "geometry" are limitations found by Hubbard et al. (2001) in their study of release variables. These factors alone make studying the shot put very difficult due to the individualization of technique. Critical factors can be found, but the method of creating those are solely dependent on the body type of the athlete.

Joint Moments

The purpose of this study is to look at the joint moments of the hip, knee and ankle of the drive leg as it turns and lifts the center of mass, creating torque on the trunk and, in turn, increasing the important release height, velocity, and angle of the shot put. Also this study will look at the joint moments of the hip, knee and ankle of the block leg, or counter leg, as it pushes back against the drive leg. Being in contact with the ground is very important to build power on the shot put (Smith, 2005). Milan Coh et al. (2008) found that much of the power generated in the form of ground reaction forces is a result of the actions of the lower extremities. Gliders and rotational shot putters both use their pivot foot in the center of the ring as the main propulsion during the throw and therefore, it is crucial to understand the forces going through the joints of the legs.

Joint Moments and Running

Being such a dynamic event, the shot put is very difficult to recreate and test in a controlled environment. Joint moment studies have been done on gait and running due to the simple nature of the movement. Studies have found that during gait and light jogging, joint forces can reach as much as 2-3 times [body weight] and during sprinting up to 4-5 times [body weight] with as much as 7 times [body weight] in the knee joint alone at peak speeds (Cavanagh & Lafortune, 1980; Seireg & Arvikar, 1975). These forces are found to contribute to overuse injuries in athletes due to the constant forces being applied through the joints of the lower extremities (Cavanagh & Lafortune, 1980; Kepple, Siegel, & Stanhope, 1997). With peak joint moments being positively correlated to the speed of running, the amount of force that may be produced by a shot putter who is using the ground force to help propel a throw to 13 meters per second must be considerably high.

Joint Moments and Dynamic Movements

More studies are being done to look at joint moments of more dynamic movements, but none are directly relevant to the shot put. Wretenberg et al. (1993) studied the joint moments of the hip and knee during different degrees of the squat. This study found that their was significant difference between 90-degrees and the parallel squat in the hip joint moment while the knee followed a different pattern in which the knee joint moment increased as the degree increased (Wretenberg, Feng, Lindberg, & Arborelius, 1993). Besier et al. (2001) studied the joint moments at the knee during unanticipated and anticipated cutting maneuvers concluding that unanticipated cutting maneuvers had higher joint moments through the knee and therefore could lead to risk of injury (Besier, Lloyd, Ackland, & Cochrane, 2000). While these studies incorporate concepts that are present during the shot put, neither completely demonstrates how forces will be applied during that final phase of the shot put. Hubley et al. (1983) have concluded that understanding the magnitude of particular muscle groups during an activity would be valuable for coaches, physiotherapists, and anyone interested in designing training programs (Hubley & Wells, 1983). By studying the joint moments of the hip, knee and ankle during the delivery phase of the shot put, we can more fully understand how to correct technique, train, and prevent injury in the shot put.

Conclusion

Research on the shot put and the joint moments through the legs are still missing. While the data collected is based on video analysis, critical factors for both the rotation and glide techniques can be determined to help athletes know where improvements need to be made. Higher number of subjects than in previous studies will help determine critical factors for both elite and the non-elite competitors. With few studies measuring joint moments or ground reaction forces within the shot put, this study desires to refine the critical factors using the collected data which will hopefully increase the shot put velocities needed to throw further and break world records.

Methods

Subjects

Eight to twelve trained male right-handed shot putters ages 18-35 years will be recruited as volunteers to participate in this study. Each subject will have participated in at least a collegiate level competition in the last three years. Participants will be trained in the rotational technique with no other techniques being accepted. The Brigham Young University's Institutional Review Board will approve the study and all the subjects will be required to sign written consent before participating in the study.

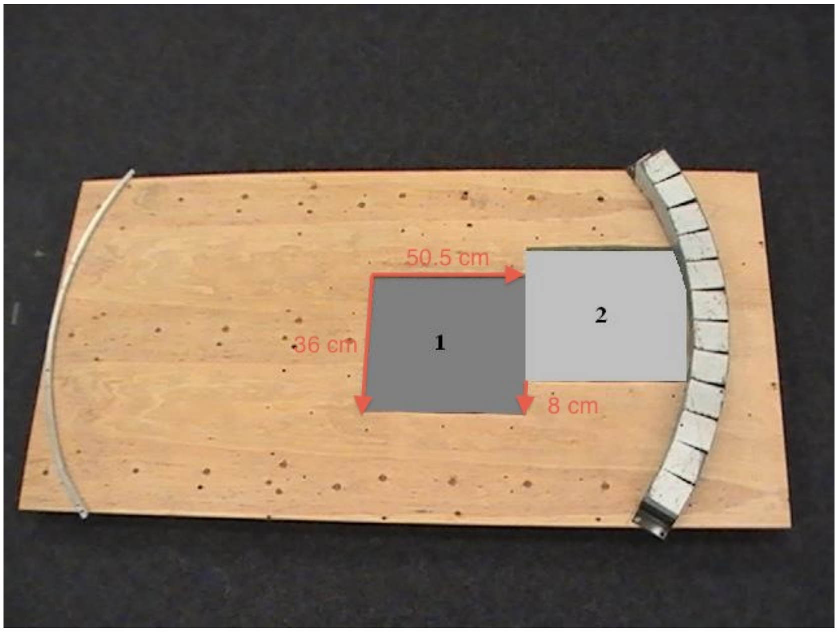
Procedures

Each athlete will be brought into the lab and asked to sign a consent form approved by the Brigham Young University human subject review board. They will be asked to provide their current body weight and their personal record in the shot put. Each athlete will be instructed to participate in three usable trials. Usable is defined as trials in which the athlete hits the force plates correctly, with one foot only touching one force plate and with no part of their foot touching the wooden surface. The athlete must complete a fair trial according to the rules of shot putting. Participants will warm up outside the lab prior to the trials to a level at which they would normally do prior to a competition or practice. Prior to collecting data, athletes will be given practice trials in the lab with and without the shot put in their hand. This will be done to insure they are comfortable with the ring surface, in the testing environment, and to properly position them so they are consistently hitting the force plates correctly. Athletes will have their body segment parameters measured and entered into the Vicon Nexus system along with their current height and body weight. After warming up, participants will complete at least three or more trials in which they will throw the competition shot (7.257 kg for men) with the rotational technique. Any subject exceeding thirty trials will be asked to return at another time to avoid the effects of fatigue. All attempts should be taken at full force and all efforts should be made to stay inside the ring to complete a fair throw.

Measurement

Two AMTI force plates (OR-6, Watertown, MA, USA) will be used for collecting ground reaction force data. Calibration of the force plate took place during manufacturing by the company. The force plate is imbedded into the lab floor and will be surrounded by a seven-foot wooden board and a toe board to be used as the throwing ring. Placement of the force plates has been determined by video collection of the feet positioning of many different throwers during the delivery phase of the rotational technique. Before each data collecting session, a few practice throws will be done in the ring to verify appropriate function of the instruments.

The Vicon Nexus system (Denver, CO, USA) with 6 MX13+, two F20 cameras, and two T20 cameras running at 320 Hz will be used to track the position of the body during the throw. To measure horizontal distance, two Casio FX25 cameras, with survey pole calibration, running at 120 Hz positioned 45-degrees from each other will capture speed and height of release using direct linear transformation (DLT). Vicon Motus will be used to manually digitize the shot put for the first eight frames before and after release. Horizontal distance will then be calculated using projectile equations assuming all other factors, such as gravity, will remain constant. The Vicon system with the Plug-In Gait module in correlation with the force plates will be used to obtain force, while 36 reflective markers will be placed on the body to track body positioning, and joint moments. Vicon Nexus will be used to calculate joint moments and will be normalized by body weight and run through a Butterworth filter.



Variables

For this study, horizontal is the independent variable while the total energy, left and right hip energy during the release phase of the throw will be the dependent variables.

Data Analysis

Simple linear regression will be calculated for the total energy with highest horizontal displacement. A mixed model regression, blocking on individual, comparing throwing distance with our three dependent variables will be used to better estimate variance and increase power of study. After data has been analyzed we will list our findings and draw conclusions on the information we have collected.

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Appendix B: Statistical Analysis

Table 3. Ratio of Total Hip Energy Change to Throwing Distance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.782[a]	.612	.547	1.4295135

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.315	1	19.315	9.452	.022[a]
	Residual	12.261	6	2.044		
	Total	31.576	7			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	12.890	1.144		11.269	.000
	Hip to Total	14.480	4.710	.782	3.074	.022

Table 4. Ratio of Left Hip Energy Change to Left Leg Energy Change with Distance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.790[a]	.625	.562	1.4051090

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.730	1	19.730	9.993	.020[a]
	Residual	11.846	6	1.974		
	Total	31.576	7			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
1	(Constant)	14.823	.629		23.547	.000
	Ratio Left Hip to Left Leg Total Power	4.246	1.343	.790	3.161	.020

Table 5. Ratio of Right Hip Energy Change to Right Leg Energy Change with Distance

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.024[a]	.001	-.166	2.2934046

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.018	1	.018	.003	.955[a]
	Residual	31.558	6	5.260		
	Total	31.576	7			

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
1	(Constant)	15.969	1.534		10.411	.000
	Ratio Right Hip to Right Leg Total Power	.311	5.313	.024	.058	.955