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Hip-shoulder separation in the javelin throw and its relationship with level of experience

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HIP-SHOULDER SEPARATION IN THE JAVELIN THROW AND ITS RELATIONSHIP WITH LEVEL OF EXPERIENCE

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By

Samantha Baker

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Signature Page

THESIS OF SAMANTHA BAKER APPROVED BY

____ DATE_________

DR. CHADRON HAZELBAKER, GRADUATE STUDY COMMITTEE

____ DATE_________

DR. JENI MCNEAL, GRADUATE STUDY COMMITTEE

____ DATE_________

DR. ALAN COELHO, GRADUATE STUDY COMMITTEE

Abstract

HIP-SHOULDER SEPARATION IN THE JAVELIN THROW AND ITS RELATIONSHIP WITH LEVEL OF EXPERIENCE

By

Samantha L. Baker

Spring 2021

The javelin throw is a technically-demanding sport and is excellent example of how the kinetic chain works starting with the landing of the drive foot (right foot) causing a chain reaction traveling up the knee to the hip, through the trunk, to the shoulder, the elbow, and then the wrist. The purpose of this study was to investigate the relationships between thrower experience and the timing and degree of hip-shoulder separation in the javelin throw. A six-camera, three-dimensional motion capture system was used to capture a 27 reflective marker model of the movement of the lower body (pelvis, legs, and feet) and upper body (shoulder and elbow) of 8 participants javelin throws from a short approach. There were no significant relationships between years of competitive experience and the timing and degree of hip-shoulder separation of high school and collegiate throwers was found. A high significant correlation was found between PVASIS and PVAC ($r = 0.714$, $p = 0.047$) along with age and PVAC ($r_s = 0.762$, $p = 0.028$). As athletes increase in age, utilization of the right hip increases, generating a greater peak hip velocity. Energy from the drive hip transfers up through the trunk and into the throwing shoulder. Thereby increasing the PVAC (throwing shoulder) will increase release velocity, overall increasing distance of the throw. Future studies should continue to investigate throwing techniques on how they affect hip shoulder separation angle and differences in timing of peak velocity of the hip and shoulder.

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Chapter 1. Introduction

The javelin has been thrown competitively in modern times since 1896 and has been a part of the Olympic games since 1908 for men and 1932 for women (IAAF, 2010). The javelin throw is a technically-demanding sport which has evolved from ancient spear hunting and warfare. Due to the high technical demand of the sport, modern day analysis methods have become an important component of performance improvement (Best, Bartlett, & Morriss, 1993). The javelin is an aerodynamically-designed implement that is controlled by the laws of physics (Gorski, 1982). Competitive javelins differ between the men's and women's events, with the men's implement weighing 800 grams, while the women's is 600 grams. They also differ in length. The men's javelin must be between 2.6-2.7 meters long, while the women's javelin must be 2.2-2.3 meters long. There are some slight differences in these specifications in youth and master's class athletes.

Training for the javelin event is often year-round in more advanced athletes but may be shorter depending on the athlete's level of experience and dedication to the sport. The training year is generally divided into three phases: preparation, pre-season, and competitive. The preparation phase is typically from September to December and is primarily focused on developing the strength and power of the athlete as well as perfecting their technical performance, with little attention paid to the distance of the throw. The next phase, pre-season, commonly extends from the end of December through March or April. While the development of strength and power continues to be important, more attention is paid to increasing throwing intensity and incorporating speed work to improve the approach. Finally, in the competitive season, strength and power gains must be maintained however the primary training goal is to fine-tune technique and maximize approach speed.

In the United States, high school athletes have access to training only during spring track season, giving them roughly one month to improve their physical and technical abilities before competition begins. Due to the limited time for preparation before the competitive season begins, coaches must primarily focus on teaching proper throwing techniques. Total training time per day is also limited to 2-3 hours per day (Washington Interscholastic Activities Association, 2019). Given these time constraints, not all aspects of technique will receive the same attention or training time. In the quest to prepare for impending competitions, athletes can develop improper techniques that may not be recognized by coaches.

Overview of Overhead Throwing

All overhead throwing activities are dependent upon effective coordination of the upper and lower extremities, and the javelin throw is no exception (Liu, Leigh, & Yu, 2014). Common to all overhead throws, the initiation of the throwing movement begins in the distal part of the lower extremity. For example, in baseball pitching, the wind-up phase involves the creation of potential energy by elevating and internally rotating the stride leg, twisting the torso away from the throwing direction and moving the center of mass to the back edge of the stance leg (Hay, 1973; Weber, Kontaxis, O'Brien, & Bedi, 2014). The muscle activity involved in this wind-up phase results in a storage of elastic energy which is then transferred upward from the lower extremities through the torso, and into the throwing arm during the subsequent phases. If sequenced properly, the end of this chain of movements concludes with high ball velocity at the moment of departure from the hand.

Hip-Shoulder Separation and the Kinetic Chain

The idea of a kinetic chain explains how joints and segments influence each other during movement or motion (Feltner, 1989; Moon, 2007; Seroyer Nho, Bach, Bush-Joseph, Nicholson, & Romeo, 2010). When one segment is in motion, it creates a chain of events that affects the movement of neighboring joints and segments. The javelin throw is an excellent example how the kinetic chain works. It starts with the landing of the drive foot (right foot) following the impulse drive (final crossover of the throw with the right leg leading the left for a right handed thrower), causing a chain reaction traveling up the knee to the hip, through the trunk, to the shoulder, the elbow, and then the wrist. Power that has been generated from the adjoining segments transfers to the javelin during the delivery or throwing phase. According to Lui and colleagues (2014), the motion during delivery is critical for maximizing release velocity of the javelin. Release velocity has been shown to be the primary factor that determines the distance of the throw (Bartlett, Müller, Lindinger, Brunner, & Morriss, 1996; Best et al., 1993; Bielk, 1984; Komi & Mero, 1985; Leigh, 2012; Maryniak, Ladyzynska-Kozdras, & Golinska, 2009; Mecklenburg, 1990; Murakami, Tanabe, Ishikawa, Isolehto, Komi, & Ito, 2006)

When throwing the javelin, the body can be conceptualized as two systems: 1) hip and 2) shoulder. When the two systems are combined, they produce an upward rotational force (Ariel, Pettito, Penny, & Terauds, 1980). The technical aspect of the timing and sequencing between the drive hip and throwing shoulder is important of achieving maximum distance of the throw (Liu et al., 2014). The drive hip follows the landing and rotation of the drive foot, to the rotation of the drive knee, and then the rotation of flexion-extension of the drive hip (Leigh, 2012). The last technical aspect of the lower body is the rotating of the hip inward, then transferring through the trunk to the upper body, starting with shoulder horizontal abduction to adduction. If the drive hip and throwing shoulder activate at the same time, there will be no pre-stretch across the trunk muscles linking the two segments (Ariel et al., 1980; Best et al., 1993; Weber et al., 2014; Young, 2008). A fast pre-stretch of these muscles enhances the stretch-shortening cycle (SCC), allowing the athlete to produce more force applied to the linked segments at a greater speed. Shoulder rotation must be delayed relative to the hip in order to generate the necessary pre-stretch to engage the SCC. Separation between the two segments has been shown to improve performance during the throwing phase in professional javelin throwers (Best et al., 1993). As reported in Best and colleagues' study, (1993) the throwers with greater timing separation between the hip and shoulder had higher release velocities (22- 28m/s). A greater release velocity has been demonstrated to be one of the main factors in increasing the distance of the throw. The study also looks at the timing of the drive hip, throwing shoulder, and elbow preceding release of the javelin. The majority of the throwers had the maximum hip velocity farthest away in time from release, followed by the max shoulder velocity, and lastly the peak elbow velocity. Throwers that had greater time between peak shoulder and peak hip velocities had higher release velocities. This suggest that the technical aspect of the sequence timing is a fundamental part of the javelin throw.

Not only does timing between the two segments influence the SCC but the degree of angle separation between the drive hip and the throwing shoulder as well. To achieve a greater timing separation between the hip and shoulder during the throw having a greater angle of separation will increase that timing, overall contributing to the release velocity of the throw, enhancing performance. According to Best and colleagues (1993), a large drive-hip-to-javelin horizontal distance should be maintained throughout the throw until block foot plant (left foot contact). The distance between the javelin and the drive hip is affected by the positioning of the shoulder.

Level of Experience and its Effects on Throwing Skills

In training any skill, the greater amount of exposure and education of the skill, increases the athletes' ability to master that specific skill. The two most influential variables to throwing development are age and sex (Butterfield & Loovis, 1993). Throwing performance gradually improves throughout childhood and early adolescence for both males and females (Lorson, Stodden, Langendorfer, & Goodway, 2013) along with coordination, balance, and muscular strength (Butterfield & Loovis, 1993). Older throwers are more likely to have learned the proper throwing mechanics and have developed the flexibility, mobility, and muscular strength to throw at a higher velocity. According to Lorson and colleagues' study, (2013) they suggest that throwing form and ball velocity change throughout one's lifespan, with most advanced skill during young-adult years (18-25 yrs) as compared to middle adolescent (14-17 yrs). They found that there is significant difference of four throwing technical aspects between adolescent and young-adults are different. Compared to adolescent groups young adults performed at more advanced levels in three technical aspects of throwing: step action ($p = 0.02$), trunk action ($p = 0.02$), and humerus action ($p = 0.001$). They further suggest that release velocity continues to increase as throwing coordination and force production continue to improve in early stages of adulthood. Sgroi and colleagues' study, (2015) also suggest that older throwers are more likely to have the proper throwing mechanics and muscle development, allowing them to throw at such high velocities. It can be suggested that throwing form and release velocity changes for both men and women throughout one's lifespan with being at the most advanced stages in young-adult years. Since release velocity has been shown to be the primary factor that determines the distance of the throw (Bartlett, Müller, Lindinger, Brunner, & Morriss, 1996; Best et al., 1993; Bielk, 1984; Komi & Mero, 1985; Leigh, 2012; Maryniak, et al. 2009; Mecklenburg, 1990; Murakami, Tanabe, Ishikawa, Isolehto, Komi, & Ito, 2006), the notion is that with age comes more experience, resulting in a farther throw.

Problem Statement

The sequence and timing of lower and upper extremity motions is an important technique factor for maximal throwing performance. According to research from Whiting and colleagues, (1991) release velocity of the javelin is affected by the orderly progression of maximum speed of the hip, shoulder, and elbow. Release velocity is also affected by age and level of experience according to Lorson and colleagues, 2013. The timing as well as the angle separation difference between hip and shoulder has been suggested to improve the SCC action of the involved muscles, improving the efficiency of the kinetic chain (Ariel et al., 1980; Whiting, Gregor, & Halushka, 1991). While previous research has compared the timing between the hip and shoulder in professional throwers, this has not been investigated in collegiate nor high-school throwers. Lower performances from these levels of throwers may be partially explained by differences in timing between the hip and shoulder as compared to professional throwers, however there are no data describing these variables in these populations. Therefore, the primary purpose of this study is to investigate the relationships between thrower experience and the timing and degree of hip-shoulder separation.

Significance

In a sport where medals are decided by centimeters, every aspect of technique must be perfected in order to maximize performance. In the javelin throw, one technical aspect that has been identified in previous research as being related to release velocity of the javelin is the degree and timing of hip-shoulder separation. Having a separation between the two segments utilizes the kinetic chain more effectively putting less stress and force on the throwing shoulder reducing possibility of injury (Howenstein, Kipp, & Sabick, 2019). While these factors have been investigated in professional javelin throwers, it is not known how throwers with less experience utilize hip-shoulder separation in their throwing technique. Understanding the relationship between the technical aspect of the hip-shoulder separation of the javelin throw and the level of performer could help inform coaches of developing athletes as to the importance of hip-shoulder separation, lead to the incorporation of appropriate training drills to improve it, and reduce the probability of a shoulder injury.

Research Question

The primary research question guiding the proposed investigation is 'Is there a significant difference in hip-shoulder separation between the throwing shoulder and the drive hip during the throwing phase in the javelin throw based upon athlete level of experience?'

Null Hypothesis

The null hypothesis to be evaluated by this research is that there will be no significant relationship between years of competitive javelin experience and the timing and degree of hip-shoulder separation in high school and collegiate throwers.

Independent and Dependent Variables

The independent variable in this study is level of competitive experience in the javelin throw measured in years. The dependent variables to be correlated are the difference in timing of peak resultant velocity of the drive hip and throwing shoulder (SEP_T, measured in seconds), and the maximal angle of separation between the two segments during the throwing phase (SEP_{A}, measured in degrees).

Operational Definitions

Table 1
*Operational Definitions**

Angle of Attack (deg)	The angle between the path of the javelins center of mass and the long axis of the javelin (Terauds,1985)
Angle of release (deg)	The angle between the horizontal plane and the path of the javelin's center of mass the instant of release (Terauds,1985)
Block foot	The final left foot plant in the delivery stance (Mecklenburg, 1990)
Block leg	The front leg (left) bracing the thrower at which the thrower is in the delivery stance.
Block arm	The left arm or non-throwing arm of the body utilized during the single support phase to assist in bracing the thrower and keeping the chest upright.
Bony Landmark	Any place on the skin surface where the underlying bone is normally close to the surface and easily palpable.
Drive knee	The right knee during the single support phase where the knee is being actively driven forward and inward aiding in the transfer of energy of the kinetic chain.
Drive Foot	The first point of contact of the right foot after the impulse drive and beginning the delivery phase. Is the beginning of the transfer of energy through the kinetic chain.
Foul Line	The curved arch line at the end of the javelin runway in which the javelin must be released behind along with no part of the thrower can touch or cross the line for the throw to be determined legal (Leigh, 2012)

Drive Hip	The right hip in the single support phase and the final portion of the lower body energy transfer of the kinetic chain.
Hip Drive Activation	When the drive hip actively rotated inward continuing the transfer of energy of the kinetic chain.
Drive Knee Activation	The rotating of the knee inward during the single support phase.
Impulse Drive	The final crossover in the crossover series, where the athlete actively drives their lead leg forward to land in the single support phase the athlete will be leaning slightly backwards.
Release Velocity(m/s)	Is the speed and direction of the javelin at the moment it has left the hand of the thrower.
Single Support Phase	The time period between the instant the drive foot contacts the ground and the instant where the block foot contacts the ground (Leigh, 2012). Is also referred to as the "power position".
Sector	The throwing area where the javelin must land to be counted as a legal throw. (Rosenbaum, 2017)
Delivery Stance	The pelvis and chest have both rotated to face the sector, the block arm has crossed over to the left side of the body to aide in bracing, and the javelin is still drawn back behind the shoulder but is actively rotating outward while the elbow and wrist rotate inward while the throwing arm is coming over the top of the shoulder (Tidow, 1996).

** Note: All definitions are referenced for a right-handed thrower.*

Assumptions

An important assumption of this study is that throwing the turbo javelin is similar to throwing a 600 gram competitive IAAF javelin. A turbo javelin is a plastic javelin which is shorter than a regulation javelin and has a larger diameter. Given that the turbo javelin is a common tool used in training for javelin throwers, this supports the assumption that it is similar to throwing an actual javelin (Howard, 2019). It also must be assumed that the throwing techniques used by the subjects will be similar to those they would use in the competitive environment. There are recognized limitations associated with laboratory testing versus that conducted in a real-world setting (Della Croce, Leardini, Chiari, Cappozzo, 2005). However, due to the desire to utilize a three-dimensional motion analysis capture system, performance must be limited to the laboratory setting.

Years of competitive experience will be reported by the subjects. It is assumed that the athletes will provide an accurate estimate of their competitive experience. In order to encourage accurate reporting, years of experience will be precisely defined and explained to the subjects verbally and in written form by the investigator. It will be assumed that years of experience is related to javelin performance, with more experienced athletes being able to throw a greater distance than those with fewer years of experience.

Participants are expected to honestly and accurately respond to all survey questions provided to them. Further, it is assumed that each subject will perform with maximal effort, and they will be verbally encouraged to do so by the investigator. An important assumption for valid motion analysis is that markers placed on the subject's body will be properly located according to published definitions for biomechanical models (Rácz, Pálya, Tákacs, Nagymate, & Kiss, 2018). In order to reduce the influence of this source of error, the primary investigator has received instruction and practice in locating bony landmarks by an experienced biomechanist. Finally, it must be assumed that the reflective markers will not move too significantly over the bony landmarks during the throw. Such movement artifact is a known and accepted source of variation in human movement trials (Akbarshahi et al., 2010).

Delimitations

Participants must have at least one season of experience throwing the javelin in competition. The implement thrown will be delimited to the 600 gram Tom Petranoff turbo javelin, which is shorter in length, made up of different material, and has a different feel than an IAFF javelin. It will be necessary to use this modified javelin device due to the indoor, laboratory nature of this research. Participants will wear training shoes instead of their javelin shoes, which have spikes on the bottom of them. This delimitation is necessary to prevent damage to the floor. A participant may not perform as fast as an approach during their throw due to not being to stop as well with only training shoes. Participants must be 15 years of age or older, since before this age most athletes have not yet been exposed to the javelin throw.

Limitations

The study will be conducted in an indoor lab setting, which limits the generalizability to an actual competitive environment. Analyzing the separation between the hip and shoulder muscle activation would be more valid if competition throws were studied, however the controlled environment of the lab offers greater repeatability of the throwing conditions.
Due to the constraints of the laboratory dimensions, the run-up distance will be shorter and narrower than that of a competitive javelin runway. The lab environment will have a shortened run-up performed on a thick rubber mat, which is not the same as a Tartan Track made of polyurethane, a typical competition surface. The dimensions of a competitive IAFF runway are 36.5 m with a minimum length of 30 m, and width of 4 m (NCAA, 2019). In comparison, the length of the lab runway will be 10.2 m, 1.65 m wide, and 1cm thick.

The implement that will be thrown is a Tom Petranoff turbo javelin (commonly referred to as a ‘long tom’) instead of an IAFF approved javelin to avoid potential damage to the lab. The turbo javelin is a common training aid used at all skill levels to teach correct throwing mechanics. Because of its light and durable design, athletes can work on perfecting their technique and accuracy (Howard, 2019).

There will be no control over the throwing technique used by each athlete, therefore the results will be limited to the techniques taught to each athlete by their coaches, who will likely have various levels of technical knowledge in the javelin event.

Finally, due to the laboratory nature of this study, we will be unable to directly measure competitive throwing performance of each subject at the time of the study. Instead, our variable of years of experience will be utilized to compare athletes who will presumably differ in their actual javelin performances, related to their years of competitive experience.

Chapter 2. Review of Literature

Evaluating the technical skill of a javelin thrower is an important component to improve performance of the throw. The javelin throw is a technically demanding sport, which has led to the incorporation of modern day analysis methods to give coaches and athletes a better way to view and understand the throw (Best et al., 1993). This review of literature will present an overview of the javelin throw history and rules and regulations during a competition to explain where the sport originates from and how it has evolved over time to the modern-day javelin throw. Following, the phases of overhead throwing and the kinematic chain of throwing will be reviewed, focusing on what motions and phases make up the throwing motion. Additionally, the importance of utilizing the whole body in the kinetic chain to improve force output and performance will be examined. Next, the phases of the javelin throw and the difference in levels of experience will be reviewed. Analyzing the three phases of the javelin throw and how the level of experience can affect utilization of kinematic aspect of the throw. Lastly, different levels of experience, release velocity and release angle, and shoulder injuries will be reviewed and their potential relationship with the hip drive in the javelin throw. Gaps in of the kinematic relationship of the utilization of the hip drive in the javelin throw will be highlighted and form the basis of the proposed study.

History of the Javelin throw

The origin of the javelin throw is from primitive hunters who would use spears to bring down large animals for food (Knighton, 2017). Spears were also used in ancient war times to add greater range and accuracy causing injury and death to the enemy (Knighton, 2017). Over time the spear evolved from a sharpened stick to having stone as the point, and then to a bronze tip in 3500 during the Bronze Age. Likewise, the usage of the spear evolved with time; spears were used as a throwing weapon and up-close during war. Pilums were a group of Roman soldiers that threw the spear at the enemy in a single volley to catch the opposing army off guard, as other soldiers charged the opposing army (Knighton, 2017). With the fall of the Roman Empire, European knights that rode horses would use lances, which were long spears to impale oncoming calvary. The Swiss infantry used pikes (a long spear) to make a wall of spears to block off oncoming calvary. Lastly, was the polearm, a mix between a spear and an ax used to stab, slash, or even pull riders down from their horses (Knighton, 2017).

The javelin throw was one of the five events in the Greek pentathlon, competition in the ancient Greek Olympic Games, Nemean Games, and Pythian Games (Zarnowski, 2013). The javelin, or Akon (Greek), was a wooden pole often made of elder wood. It was about the height of a man and slightly thicker than a finger. A leather strap called an ankyle (Greek) was wrapped around the shaft and used to aid in throwing the spear. The tip of the javelin was designed differently depending on its function since in athletics it is not a lethal weapon (Sweet, 1987). The first recorded world record was in 1896 (35.81meters), moving forward to the 1984 world record of 104.8 meters (Mecklenburg,1990). In 1986, the IAAF instituted a new javelin design. The center of mass of the javelin was moved forward by four centimeters, resulting in an overall reduction in the distance of the throw as well as increasing the likelihood of the javelin landing tip-down (Lawler, 1993). Initially, there was an outcry from coaches and athletes alike that the new javelin would change the nature of the sport (Lawler, 1993). Despite this early controversy, the modern-day thrower has adapted their technique and training to the new design, and the event is as popular as ever. With the evolution of the technique of the throw, throwers have had to accept full “responsibility” of the throw. The new implement no longer floated but instead had to be driven, forcing throwers to return to ‘pure’ technique (Lawler, 1993).

Rules and Regulations of Javelin Competition

The current rules and regulations of the javelin throw are maintained by the International Association of Athletics Federation (IAAF), founded on the 17th of July 1912. The IAAF was founded as the world governing body for the sport of track and field athletics (Blackburn, 2019). There are specific regulations on the javelin implement to maintain fairness throughout competition. The implement consists of three parts: a metal tip, a shaft (made of light metal), and a cord grip (Rosenbaum, 2018). It is aerodynamically designed to closely follow the laws of physics (Gorski, 1982). The javelin thrown by females is shorter (between 2.2-2.3 meters) and lighter (600 grams) compared to that thrown by makes (between 2.6-2.7 meters, 800 grams) (Rosenbaum, 2018). The IAAF rules state that the runway must be between 30-36.5 meters long, the thrower may have as long or short of an approach as desired as long as it fits within the runway. The throwing area in that the javelin must land is called the throwing sector. It must create an arc of 28.96˚, with a ratio of 2:1 length by arc width ("Sector Angles") with the sector lines having a ratio of 2:1 length by arc width. To be considered a legal throw the javelin must be thrown over the shoulder or the upper part of the throwing arm (Blackburn, 2019). No part of the thrower may not cross the foul line at any time or use any foul language, otherwise, the throw will be considered a scratch (Blackburn, 2019). Lastly, a thrower cannot turn their back to the sector prior to the landing of the javelin, otherwise, the throw will be considered a scratch (Blackburn, 2019). There are different regulations between college and high school with marking the distance of the throw. Marking the distance thrown differs depending on the level of competition. In high school, the part of the javelin that makes the first contact with the ground is where the throw is marked. However, if the throw lands flat then the distance will be marked at the back of the handle. In collegiate and professional competition, the javelin must travel in a downward arch, hitting tip first to be counted as a legal throw. In preliminaries, each thrower is allowed three throws; if the thrower advances to finals they are allotted an additional three throws (Blackburn, 2019). The current world record of the men's javelin throw is held by Jan Železný at 98.48 meter in 1996 and the and the current women's world record is held by Barbora Špotáková at 72.28 meter in 2008 (IAFF, 2010).

Phases of Overhead Throwing

In order to understand the evolution of the javelin throw, much can be learned from the kinematics of overhead throwing. Overhead throwing is a fundamental movement skill that should be taught to children to demonstrate movement competency (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). While each specific type of overhead throw (football, baseball, javelin, etc.) has its own definable characteristics, they share a generalized movement pattern that has been divided into six phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow through (Wilk, Meister, Fleisig, & Andrews, 2000).

Wind-Up

The wind-up phase begins when the athlete initiates the first motion of throw. (Wilk et al., 2000). The initial movement of the throw begins with the contralateral lower extremity (Seroyer et al., 2010). Keeping the center of mass over the back leg, this allows the thrower to generate maximum momentum (Seroyer et al., 2010). This phase ends once momentum is being transferred forward.

Stride

According to Wilk and colleagues (2000), the stride phase begins at the end of the wind-up phase when the left leg begins to fall to the ground. During this phase, the athlete is actively driving their right knee and hip forward with concentric contractions lengthening the stride. Throughout the stride phase, the trunk is kept closed (perpendicular towards the throwing sector) and the throwing arm is behind the trunk, horizontally abducted. Eccentric contractions of the hip flexors control the lowering of the block leg. As the block leg contacts the ground, the hip on that leg (left) begins to externally rotate at the same time the drive hip internally rotates. Once the block leg has touched the ground this is the end of the stride phase.

Arm Cocking

The third phase begins when the block foot contacts the ground and ends when the shoulder is maximally externally rotated (Wilk et al., 2000). This phase lasts between 0.1-0.15 seconds with the trunk rotating to face the sector. The block leg contracts eccentrically to decelerate knee flexion, quickly transitioning to isometric contraction to stabilize block leg during this phase (Wilk et al., 2000). Both hips are now internally rotated, facing the sector, this producing a recoil effect for shoulder rotation due to the stretching of the trunk. Once the hips begin its rotation, the upper torso begins to transversely rotate, then having the abdominal and oblique muscular system stretched resulting in hyperextension of the lumbar trunk. During this time, a great amount of energy is imparted to the system. The trunk then rotates facing the sector, while the throwing shoulder horizontally adducts 80˚-100˚, with the forearm and hand behind the shoulder, externally rotated approximately 165˚- 180˚ (Wilk et al., 2000). It can be seen from Figure 1. The forearm is horizontally positioned about 90˚ backward from vertical. The end of the arm cocking phase is when the leg, hip, and trunk have completed their acceleration (Weber et al., 2014). This has been deemed as a “critical moment” due to the tremendous amounts of force on the glenohumeral joint (GH joint). Adaptive and pathological changes occur to the shoulder and elbow from the excessive external rotation and range of motion (Weber et al., 2014).

Arm Acceleration

Weber et al. (2014) describes this phase as beginning when the GH joint is at maximum external rotation (MER) and transitions from external rotation to internal rotation. The triceps, pectoralis major, latissimus dorsi, and serratus anterior contract concentrically to reverse the arm cocking phase and begin the internal rotation and at the same time, the elbow flexors are concentrically contracting to control elbow extension. The trunk transitions from a hyperextended position to a forward flexed position, the block leg extends, and at the end of the acceleration phase, the elbow is fully extended. Once the implement has been released, this is the end of the acceleration phase.

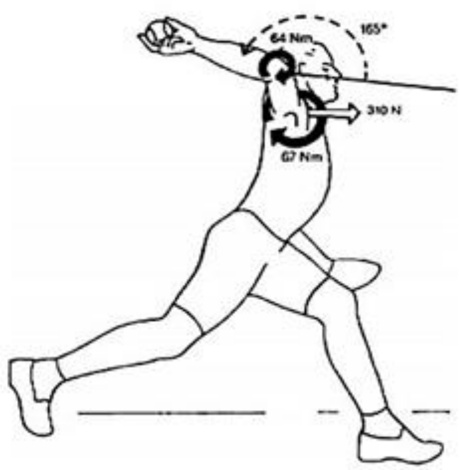

Figure 1 The last part of the cocking phase, where a significant amount of amount of load is generated on the glenohumeral joint (Wilk et al., 2000)

Arm Deceleration

This phase defined by Weber and colleagues (2014) begins once the implement has been released. The throwing arm continues forward, horizontally abducting across the chest and internally rotates. After release, large eccentric loads are needed to decelerate the throwing arm, which is extended at the elbow, abducted at the shoulder causing GH distraction. To prevent subluxation of the GH joint, the rotator cuff muscles contract, at the same time elbow flexors eccentrically contract. When the shoulder reaches maximum internal rotation is the end of the phase.

Follow-Through

The last phase of the throw consists of the throwers body weight and momentum over the block leg. The trunk moves into a flexed position over the block leg for stability with the drive leg following behind to "catch the body" and the throwing arm continues to decelerate (Weber et al., 2014). Energy generated during throwing must be dissipated safely during deceleration and follow-through to reduce overuse injuries (Weber et al., 2014).

Importance of Kinetic Chain in Overhead Throwing

A kinetic chain is where joints and segments influence each other during movement (Seroyer et al., 2010). When one segment is in motion, it creates a chain of events that affects the movement of neighboring joints and segments. The more body segments that contribute to the total force output, the greater the velocity at release (Wilk et al., 2000). Throwing is a dynamic activity of an open-ended kinetic chain of segments working from a proximal (lower extremity) to distal (upper extremity) sequence (Oliver, Washington, Barfield, Gascon, & Gilmer, 2018). The motion of each segment in the chain maintains the transfer of energy, but also increases energy (Wilk et al., 2000). Wilk and colleagues describe the kinetic chain in overhead throwing starting with 1) the lower extremity, 2) pelvis, 3) spine, 4) shoulder girdle, 5) upper arm, 6) forearm, 7) hand; each segment starts as the adjacent proximal segment reaches its top speed (Seroyer et al., 2010). The muscles of the lower extremity (quadriceps, hamstrings, hip internal and external rotators) coordinate together to provide a stable base for the trunk to rotate and flex during throwing (Seroyer et al., 2010). Since the lower extremities produce most of the force during the throwing motion, a dysfunction to the proximal segment can result in reduced energy transfer and debilitation of the shoulder and elbow (distal segments) (Oliver et al., 2018). Success achieved from an efficient kinetic chain, requires strength, flexibility coordinated muscles activation, and properly executed biomechanics (Meron & Saint-Phard 2017). According to Seroyer (2010), in supporting previous findings of Kibler and Chandler, they found that a 20% decrease in kinetic chain energy delivered from the hip and trunk to the arm would require an increase of 34% of rotational velocity from the shoulder to be able to achieve the same amount of force to the hand. Efficiency in the kinetic chain reduces the contribution of the shoulder joint, putting less stress on it and potentially decreasing injury to the joint (Seroyer et al., 2010). Seroyer also states that with greater knowledge of the kinetic chain and key parameters of the throwing motion can greatly improve technique, performance, rehabilitation, and injury prevention.

Specific Phases of the Javelin Throw

The javelin throw is divided into three phases: the approach, crossover series, and the throwing phase. The kinematic sequences of the upper (shoulder, elbow, wrist) and lower extremities (hip, knee, ankle, lower trunk, and upper trunk joint) are extremely important in the performance of the javelin throw (Liu, Leigh, & Yu, 2010).

Approach

The goal of the approach phase is to increase the velocity of the thrower-javelin system. It has been shown that the faster the approach speed, the farther the throw (Bartlett, Muller, Lindinger, Brunner, & Morriss, 1996). During the approach, the athlete is in an upright running posture with the javelin held about head height in a stationary position while the free arm swings in a relaxed position (Tidow, 1996). The number of strides taken in this phase depends upon the thrower's comfort with the speed while still accelerating during the approach.

Crossover Phase

Transferring into the crossover phase, the javelin is drawn back with the chest, shoulders, and hips of the athlete perpendicular to the toe board of the runway (Figure 2). Think of the athlete as parallel with the runway. The two main types of drawbacks that are used throughout the world are the Finnish and the Swedish (Tidow, 1996). In the Finnish and Swedish model, the javelin arm is extended horizontally to the runway and is relaxed with the tip of the javelin next to the athletes' temple, the shoulders are in line with the throwing direction, and the feet are pointed straight forward (Tidow, 1996). The number of steps depends on the thrower, ranging from 5-9 steps.

Throwing Phase

The final crossover leads into the throwing phase with an impulse stride (Figure 3 and 4) that is 30-60% longer than a regular crossover stride (Tidow, 1996). An impulse torque (a driving force that causes rotation) is created by a leaned-back position going into the single support phase caused by the impulse stride. At this point, the athlete should be at their fastest speed in the approach. There will be a downward movement of the javelin's center of mass during the support contact to absorb impact (Tidow, 1996). Once the drive foot (back foot) hits the ground it transitions into the throwing phase (Figure 5). The driving on the leg in the throwing phase can only be achieved if the athlete keeps their drive foot and knee at about a 45˚ angle. If the foot lands perpendicular to the runway, then the foot cannot roll over and accelerate (Tidow, 1996). While the drive foot is rotating over, the thrower is actively driving the knee on the same leg forward while the block foot (left foot) and straight block leg are landing. The position of the drive foot after it rotates is with the heel of the foot towards the sky and the lateral side of the foot in contact with the runway. Following the knee drive, the ipsilateral hip drives forward, then the block arm (free arm) is pulled back from a horizontal position to being tucked by the ribs of the contralateral side of the javelin arm. The pulling initiates the whipping of the throwing arm. The shoulder is horizontally abducted and externally rotated during the throw (Figure 6). Following release of the javelin, the thrower follows through stepping over with the drive foot to catch the body from trying to stop immediately after a sprint.

Sequences of Approach: Drawback to Release

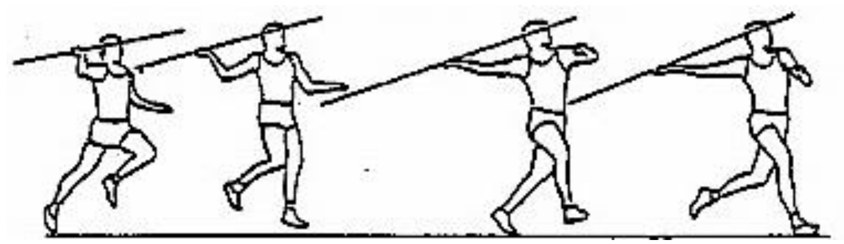

Figure 2. Drawback phase of the run-up (Tidow, 1996)

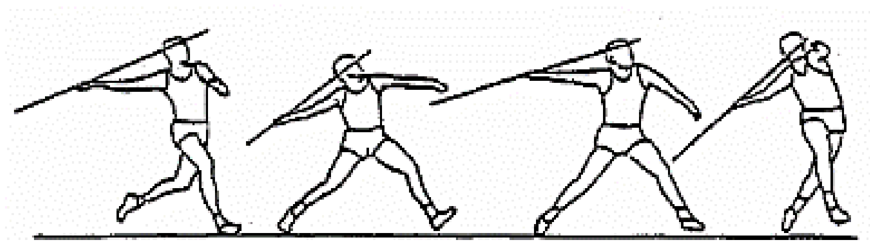

Figure 3. Crossover step leading into the impulse stride (Tidow, 1996)

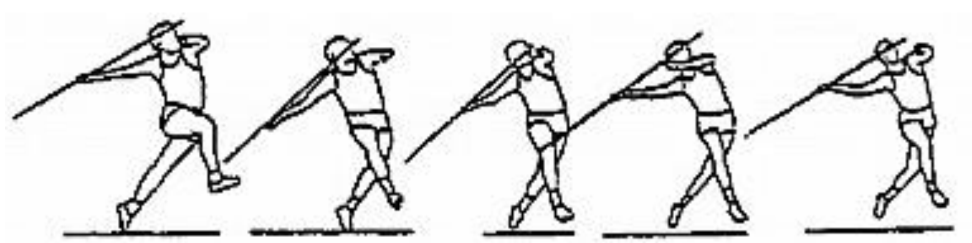

Figure 4. Comparative presentation of the push-off (1,2) and flight during impulse drive (Tidow, 1996)

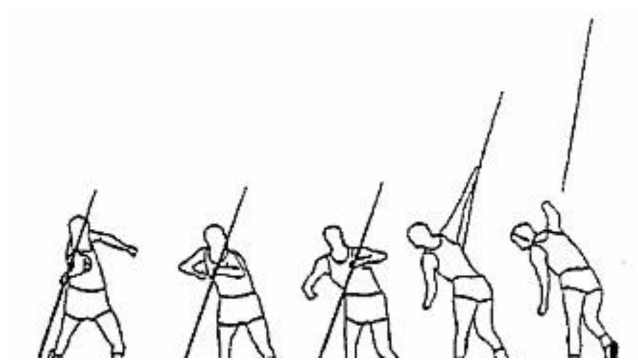

Figure 6. View from behind of the throwing arm "coming over the top" to release (Tidow, 1996)

Importance of Approach Speed

Maintaining or increasing approach speed throughout the throw is one of the fundamentals of the throw. Throughout the approach the athlete must accelerate so that the last two steps of the throw are the fastest (Gorski, 1982). The speed of the approach depends on each athlete's technical preparedness; the more technically expert the athlete is, the faster their approach and vice versa. If an athlete takes on an approach that is too fast for their level of skill, then they will falter in some aspect of the throw reducing distance of the throw. The same can be said for the opposite as well. An athlete who has more throwing experience and is more technically sound but does not utilize enough speed in their approach does not allow them to fully utilize the technique they have mastered to cause the whipping action of the arm. Younger athletes with less experience may slow down into the impulse drive to be able to control the throw more. The end of the throw is where the athlete should be the fastest, and by having a follow through after the throw all the momentum built from the approach will be added into the throw.

Kinematic Differences in Different Levels of Experience of Throwing the Javelin

With regards to release velocity, throwers with more experience have larger release velocities compared to novice throwers and achieve a greater distance of the throw (Bartlett et al., 1996). Elite throwers can utilize forward velocity of their center of mass at release more than novice throwers. Throwers with more experience can control forward velocity during the impulse drive and after release. More simply stated, they can run at a faster speed during the approach and are able to stop themselves from crossing over the toe-board to avoid a foul. Bartlett and colleagues (1996), state that having a greater approach speed, a longer approach, and greater peak release velocity of the throwing arm segments (elbow, shoulder, and hand) will result in a greater release velocity. Overall, the increase in the level of experience is associated with a greater release velocity of the javelin.

Kinematic aspects of the throw also improve with experience and age (Lorson et. al, 2013). Being able to separate the lower body from the upper body, separate activation of the left and right arm during the throwing phase, and much more. Compared to novice throwers, experienced throwers are able to achieve a greater distance from the grip of the javelin to the right hip, in simpler terms, they are able to maintain an extended arm position with the javelin drawn straight back (Bartlett et al., 1996). The throwing arm itself peaks in linear velocities of the right shoulder, right elbow, and right hand relative to the center of mass were found to be significantly greater values, in each case for the elite group compared to both other groups (Bartlett et al., 1996).

Hip Drive Utilization in the Javelin Throw

Leading the throw with the hips is one of the basic fundamentals of the throw according to Gorski (1982). The right hip of a right-handed thrower becomes more important during the impulse drive, also called the final crossover, and into the single support phase. The position that the right leg lands in from the impulse drive effects the positioning and utilization of the hip during the throw. When throwing the javelin, the body can be thought of as two systems: 1) the hip and 2) the throwing shoulder (Ariel et al., 1980). When the two system forces are combined, it produces an upward rotation force, utilization of the hip rotation allows the transfer of momentum more efficiently. According to Ariel et al. (1980), when analyzing professional javelin throwers, the authors found that with one athlete his hips were turned to face the throwing sector. This prevents the hips from contributing to the throw because they cannot twist and transfer momentum from the hip to the shoulder forcing the arm velocity to be exceedingly high.

Having too high of velocity and stress on the shoulder can potentially result in an injury. If a thrower does not utilize right hip rotation the thrower will move from right to left when throwing forward (Ariel et al., 1980). According to Seroyer et. al (2010) in association with previous findings of Kibler and Chandler, it was found that a 20% decrease in kinetic chain energy delivered from the hip and trunk to the arm would require an increase of 34% of rotational velocity from the shoulder to be able to achieve the same amount of force to the hand.

Lui et al. (2014), investigated the velocity of each body segment during the throwing phase of a right-handed javelin thrower. The sequence of maximum joint linear velocities was hip, shoulder, elbow, and wrist. What the authors found was the velocity the hip peaked at 0.45 seconds into the throwing phase at 6 m/s, the velocity of the shoulder at about 0.6 seconds into the throwing phase 7.5 m/s, the elbow at approximately 0.82 seconds into the throwing phase 11 m/s, and the wrist at 0.9 seconds into the throwing phase 7 m/s. This demonstrates the timing of each segment and how the velocity is transferred and added to each segment to have peak velocity of the javelin at release. If the velocity of the hip is not utilized then peak release velocity will either be lower or as mentioned earlier, to achieve the same release velocity the shoulder will have to contribute more.

Release Velocity and Angle of Release in the Throwing Phase and their Relationship to the Kinetic Chain

The angle of release and release velocity (also defined as release speed) are the two most important factors that determine the distance of the throw. While release velocity is the most important aspect that determines the distance of the throw, release angle has a great impact on how effective the release velocity is to the distance of the throw. According to Bartlett and colleagues (1996) release speed is expressed as the sum of the thrower's center of mass velocity and the velocity applied to the javelin by the thrower during pre-release. The distance thrown has an approximately quadratic relationship with release speed. What this means is that distance and release speed work together in the equation $y = ax^2$, distance as the x^2, y as the release speed, and a as the constant. The equation makes a parabola which is the exact representation of projectile motion (a parabolic path). Improvement of release velocity can result from optimizing the kinetic chain (Seroyer, 2010). Included with release velocity, is release force, defined as the difference between the path of the javelins flight at release and the path of force or power exerted on the javelin by the thrower (Gorski, 1982). This results in the angle of force (the difference between path of flight and line of throwing power). The angle of release or angle of attack is the second most important factor that determines the distance of the throw. The angle of attack is a direct result of the angle of force (Gorski, 1982), with the optimal angle of release is between 32˚-36˚ due to the throw being a positive projection with the release height higher than the landing height (LeBlanc & Mooney, 2004). The release angle, or angle of attack, is divided into the angle of attitude (the orientation of the javelin to the ground) and the angle of the resultant velocity vector (the flight path of the javelin's center of mass) (LeBlanc & Mooney, 2004). Leblanc and Mooney also found that the mean attitude angles at release for men were 31° with a release angle of 34° and 40° for females with a release angle of 34°. This implies that men have a less degree difference between the javelin center of mass at release and the javelin orientation to the ground, resulting in a smaller angle of attack. Since women generate a lower release speed (LeBlanc & Mooney, 2004) a greater difference is created between the two aspects resulting in a larger release angle. The smaller release speed is a defining factor in why women do not throw as far as their male counterparts.

Javelin throwers vary in their technique, body shape, and fitness level. With any individual thrower there is a release velocity and release angle sensitivity from the nominal velocity (V_N), defined as maximum release speed capability of a thrower at a release angle of 35° (Best et al., 1993). Figure 7A and 7B are an example of how the release angle and the release velocity both have an effect on distance of the throw.

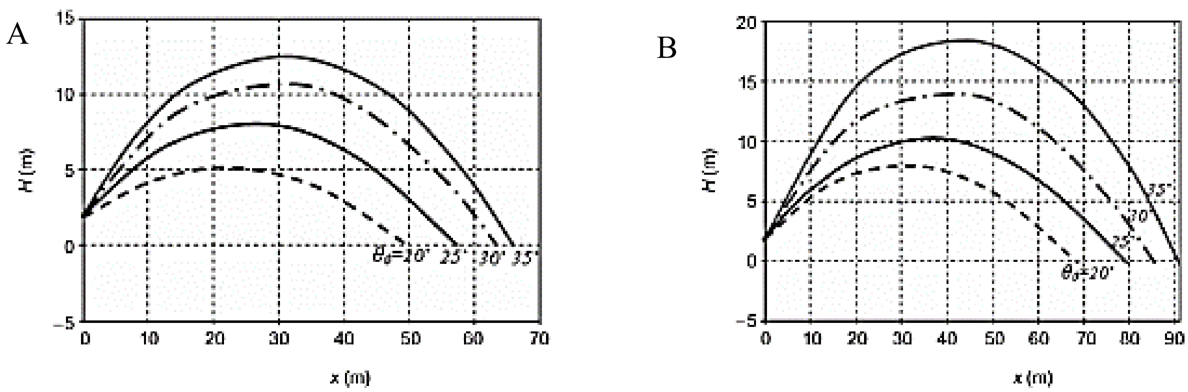

Figure 7A. The distance of the javelin throw with a velocity of 25m/s with different release angles(Maryniak et al. 2009).

Figure 7B. The distance of the javelin throws with a velocity of 30m.s with different release angle (Maryniak et al., 2009).

Potential Shoulder Injuries Associated from Lack of Utilization of the Kinetic Chain in the Javelin Throw

Throwing injuries are common and expected in a sport where the position of the glenohumeral joint is not natural. The shoulder is the most frequently injured joint in overhead throwing, with impingement syndrome as the most common cause of pain (Henning, Plumer, & Oliver, 2012). Even with "perfect" technique, overuse injuries still can occur due to the large forces and torques on the shoulder when it is maximally externally rotated and then rapidly maximally internally rotated (Weber et al., 2014). Muscle imbalance, weakness, injury to lower extremities involved in the kinetic chain, and improper technique can all lead to a potential shoulder injury. Throwers' shoulders also need to be flexible to allow extreme amounts of external rotation, while also being stable to prevent subluxation of the shoulder joint (Wilk et al., 2000). The legs and trunk are the main force generator of the kinetic chain (Seroyer et al., 2010); the muscles of the shoulder complex alone cannot generate enough energy to produce a long throw (Wilk et al., 2000). The scapula is key to facilitating the transfer of energy to the hand providing efficient stability and mobility (Oliver et al., 2018). If there is scapular dysfunction or weakness, optimum energy transfer is not capable of adding additional stress to the anterior shoulder stabilizers (Seroyer et al., 2010). If there is less utilization of the kinetic chain in the initial phases of the throw, it may cause large torque on the shoulder joint leading to potential injury (Howenstein et. al, 2019; Sgroi et al., 2015; Wilk et al., 2000; Seroyer et al., 2010).

Soft Step vs. Active Drive during the Impulse Drive and its Effect

Currently, there is a debate between throwers and coaches on whether the soft step or an active right leg is more beneficial during the impulse drive. A soft step is a passive right leg after the right foot has touched following the impulse drive transferring all body weight and momentum forward without slowing down into the block leg (Gorksi, 1982). An active right leg is where the athlete is actively pushing forward with the right leg at initial contact following the impulse drive towards the block leg to add momentum to the throw (McGill, 2010). According to Gorksi (1981), there are many advantages of the soft step technique, however it takes more time to master, but once mastered, it will aide in increasing speed during the throw. The soft step technique allows the thrower to land in a powerful position without sacrificing momentum of the throw all the while utilizing large muscle groups. This technique allows the hips and center of mass to quickly pass over the right leg, so that the block leg jolts the hips to start the throwing process. While the hips pass over the right leg, the right knee bends allowing forward movement of the hips without affecting positioning of the center of mass. The technique allows for a fast plant of the block leg after the impulse drive, maintaining most of the momentum of the approach. If the soft step is executed correctly, the phases during the throwing phase will be; the hips leading the throw with a noticeable backward lean, the block leg will land quick and straight stabilizing the hip, and the throwing arm is delayed. The soft step is to not be thought of settling on the right leg but is a passive movement by the right knee and leg that positions the center of mass in a forward thrust. This can be more simply defined as keeping the hips ahead of the rest of the body while not losing any forward momentum going into the block.

The other technique used by many elite throwers is an active right leg. When the drive foot lands after the impulse drive the right leg is actively turning the drive foot over, driving the right knee down, and turning the right hip, all prior to the plant of the left leg. The drive foot lands angled forward with heel off the ground, shoulders parallel to the runway, and the hips have a small angle towards the front. This allows the throwers center of mass to move forward unimpeded and because of the position of the foot there is little possibility to injure the leg. Once the left foot touches the ground the hips will already be forward from the constant driving of the right hip forward horizontally. Once the hips are forward the activation of the right leg is complete. Throughout this whole process the throwing arm is kept drawn back until the last second to throw. According to McGill (2010) having an active right leg prior to the plant of the block leg aides in increasing acceleration during the delivery stride. Even though according to University of North Carolina biomechanist Steve Leigh, there is no evidence for or against a soft-step or passive right leg, that may only be due to a lack of research (McGill, 2010).

Hip-Shoulder Separation Sequence

Hip-shoulder separation in the javelin throw is an example of how the kinetic chain works in a proximal-to-distal sequence (ground contact to throw) with multiple body segments (Kreighnaum & Barthels, 1985; Marshall & Elliott, 2000; Liu, Leigh, & Yu, 2014; Zernicke & Roberts, 1976). According to Ferdinands and colleagues (2013) the kinetic chain, (referred to by the authors as the ‘kinetic link principle’), can potentially activate the SCC between adjacent segments in a proximal-to-distal sequence. The SCC is an active stretch of a muscle followed by an immediate shortening of that same muscle (similar to the actions of a rubber band) producing kinetic energy (Young, 2008). The greater the pre-stretching of muscles between adjacent segments will produce a more powerful concentric contraction of the muscles resulting in a greater power production (Ferdinands et. al, 2013). From Ferdinand’s and colleagues’ study, they demonstrated that the order of the kinetic chain in cricket fast bowling was the pelvis, thorax and then the arm segments. This follows a proximal-to-distal segment kinetic chain property. Cricket bowling has been found to be similar to throwing kinematics of the javelin throw. The timing of the largest segments in the throwing sequence play and important role in the release velocity of the implement, and the timing of their motions initiates the sequence of the kinetic chain and the transfer of momentum to the distal segment (the javelin implement) (Kreighbaum & Barthels, 1985; Marshall & Elliott, 2000). Portus, Mason, Elliott, Pfitzner, and Done 2004 study found that the timing of maximum hip-shoulder separation angle after front foot contact was moderately correlated with implement speed (r = -0.340). In Ferdinand’s and colleagues’ study (2013), it was found that approach speed as well as the order of segmental rotations from proximal-to-distal sequencing effects the maximum kinetic energy of the hip-shoulder separation and are two variables for the SCC in overhead throwing. Another variable is angular acceleration of the shoulder. This causes inertial lag of the throwing arm thereby pre-stretching the anterior musculature, leading to more powerful contractions during the throwing action (concentric phase). Since the anterior shoulder musculature assists the circumduction of the throwing arm, the pre-stretch of the muscles caused by hip-shoulder separation provides an explanation of the acceleration phase of the throwing arm (Kreighbaum & Barthels, 1985).

Hip-shoulder kinematics are associated with both the timing of maximum throwing arm circumduction and maximum thoracic rotation, both of which are associated with release velocity. Increasing release velocity will aid in increase the distance of the throw improving performance.

Even with the research that investigates the utilization of the hip-shoulder separation and its contribution to performance in overhead throwing, there still is a lack of research on the kinematics of the separation of the two segments during the throwing phase of the javelin throw. Most research done on the hip-shoulder separation in the javelin throw studied professional throwers. There is a lack of representation of novice throwers or college-level throwers in this aspect of the throw. Research needs to further examine the utilization of the segment to create as much of a separation of the two segments, increasing the SCC, overall increase release speed of the implement, resulting in greater performance.

Chapter 3. Methods

The purpose of this study was to determine if there is there a significant difference in hip-shoulder separation timing and angle between the throwing shoulder and the drive hip during the throwing phase in the javelin throw based upon athlete level of experience. High school and collegiate javelin throwers performed throws with a training javelin (long-tom) in an indoor laboratory setting while their motions were recorded by a three-dimensional (3D) motion analysis system. This chapter will explain the characteristics of the sample and the methods that will be used for participant recruitment. Further, the equipment that was used will be described, as well as the biomechanical model that was used to quantify the kinematic dependent variables. Finally, a description of the data analysis procedures and statistics to be generated will be provided.

Participants

A convenience sample of physically active females in the sport of the javelin throw between the ages of 14-24 years were recruited for this study. The choice to recruit only females is due to the investigator's access to this population, and their greater numbers in the local area. Participants were recruited from the greater Spokane area for high school athletes. For recruitment of collegiate athletes, Eastern Washington University, Whitworth University, and Spokane Falls Community College were contacted, however only throwers from Eastern Washington University and Spokane Falls Community College contributed to this data set. Head track and field coaches of the higher education institutions were contacted via email and text message for the recruitment of their athletes for this study. High school head female track and field coaches as well as javelin coaches were contacted via email for the recruitment of athletes that throw the javelin at their school. The primary investigator is currently involved within the local track and field community as a volunteer assistant throws coach at Eastern Washington University (EWU), a private high school throws coach, and threw competitively at EWU, a local high school, and a local throwing club. From the previous and current affiliations with the track and field community in the Greater Spokane area the researcher has familiarity with the coaches to gain consent for contacting their athletes. Participants had to be free from injury or pain that would limit their ability to throw a javelin with maximal effort.

Sample size was determined by examining the sample size used in a related study (Bartlett et al., 1996; $n = 6$), as well as from a sample-size calculator (UCSF Clinical & Translational Science Institute, 2019). Using a two-tailed test of significance of $p \leq 0.05$, a power of 0.80, and a high correlation value (r) of 0.70 or higher, a sample size of $n = 13$ was suggested. However, due to the COVID-19 virus restrictions on face-to-face interactions that occurred during the data collection period of this study, data was only collected on 8 participants.

Instrumentation

Participants threw a Tom Petranoff 600 gram Turbo javelin (Throwing Zone Athletics, Vista, CA). The Turbo javelin is a polyethylene plastic javelin with a rubber nose made of soft elastomer rubber (Figure 8A and 8B). Participants threw the Turbo javelin into a large plastic tarp suspended from the ceiling of the laboratory and covering a portion of one wall. The tarp was used to dampen the impact of the Turbo javelin into the wall, as well as to reduce the rebound of the Turbo javelin following impact. An area of 1 m x 1 m square was marked on the tarp using white athletic tape to represent the target at which participants must throw the Turbo javelin. Throwing into a target is a typical practice drill used in javelin training and should not represent an unusual throwing condition for most participants. Dimensions of the target were based upon the average size of a hula hoop which is commonly used to teach throwers to achieve certain release angles. The top line of the target was placed 60 cm vertically from the top of the tarp and the bottom of the target was 40 cm below the top line. The height of the target was based upon the optimal release angle between 32˚-38˚ from behind the toe board line (Maryniak et al., 2009). Release angle was measured using Clinometer app on a phone, taken from behind the toe board because to be counted as a legal throw in a competition no part of the body can cross the line (Blackburn, 2019). The participants performed their approach run on a rubber matted runway (10.2 m long, 1.65 m wide, and 1cm thick). Participants had a total of 10.2 m for their approach from the beginning of the runway to the toe board. The toe board was 3.25 m away from the wall which was adequate space for the participant to avoid being hit by the rebound of the turbo javelin.

Figure 8A. Length difference between an IAFF javelin (left) 2.2-2.3 m long, and a Tom Petranoff Javelin (right) 1.83m long

Figure 8B. The difference in grip width and texture between a Turbo Jav.(right); 37mm wide and plastic compared to an IAFF javelin (left) about 150mm wide and made of cord.

3D Motion Analysis

Motion data were collected using a six-camera (Prime 13, NaturalPoint, Corvallis, OR) 3D motion analysis system using OptiTrack Motive software version 2.1.2 (NaturalPoint). The cameras detect markers within a 40 ft range, have a 1.3 megapixel resolution, 240 fps frame rate, and a latency of 4.2 ms. Model data was exported to Visual3D software v6 (C-motion, Germantown, MD), where kinematic data were calculated.

Procedures

Following approval from the Institutional Review Board at Eastern Washington University, high school and collegiate javelin throwers were recruited to participate in the study. Participants were recruited via email and text message to head coaches and javelin event coaches in the surrounding area. Emails consisted of an introduction of who the researcher is, her background in the field of the javelin, the purpose of the study, potential benefits of the study, location and instrumentation used in the study. Coaches were asked to inform all female athletes that have previously competed in the javelin throw for their respective school during the most recent Outdoor Track and Field season (2018/2019) of this research opportunity. Included in the email was the consent form, a flyer for the coaches and athletic directors to give the athletes, and the investigator contact information (cell phone number and email). Following the initial email, if no contact had been after two days another email was sent to the head coach. If the coach approved of access to the athletes, then the investigator coordinated an introductory meeting with interested athletes. If a minor was interested in the study, they were instructed to gain their parent(s)/guardian(s) permission first to participate in the study. Following parental permission, the athlete's parent(s)/guardian(s) was then instructed to contact the investigator. When the investigator was contacted by a potential participant, an email was sent to the athlete and/or parent(s)/guardian(s) including: the criteria the athlete must meet to participate in the study, a consent form, and a brief background about the study.

Participants were females between the ages of 14-24 years and were currently competing in the javelin throw at their respective school. Participants were instructed to refrain from strenuous physical activity 24 hrs prior to their data collection session. Participants were asked to wear dark-colored, non-reflective clothing to enhance the contrast between the reflective markers and the participant. Tight-fitting clothing was necessary in order to minimize motion artifact of the reflective markers. In the event that participants did not have clothing that met these requirements, clothing items in a variety of sizes were provided by the investigator. Participants were asked to wear a dark-colored sports bra either with or without a tight-fitting tank-top, at their discretion.

When participants came to the lab their signed consent form was gathered, and they were given a general background of the study. They were then verbally asked if they (or the parent in the case of minor participants) had any questions or concerns about their participation. The throwing questionnaire (refer to Appendix A) was then collected or completed in the event that a participant had not yet done so. The throwing questionnaire consisted of basic throwing and demographic information. Then height and weight were measured to the nearest millimeter using a stadiometer (Seca® 213, Chino, CA) and to the nearest pound using a physician's scale, respectively.

Warm-up

Participants performed a 5-minute general warm-up (Frikha, Chaâri, Mezghanni, & Souissi, 2016) by cycling (approximately 60 rpm at 0.5 kp) on a stationary ergometer (Monark 828E; Vansbro, Sweden). Following the general warm-up, the participant performed a specific, dynamic warm-up led by the investigator. The specific warm-up consisted of dynamic stretching activities designed to prepare the major muscle groups involved in javelin throwing, as well as throwing exercises using a 600 gram knockenball. A knockenball is a rubber ball filled with sand that is a commonly used training device for javelin throwing. The knockenball has a "notch" knob design that allows simulation of the javelin grip. Participants performed ten standing throws followed by several approach throws (three 3-step, two-five step, and two 7 step). In the event that a participant did not normally utilize a 7-step approach, she instead performed two additional five-step throws. Once the general and specific warm-up activities were completed, the participant was prepared for motion capture.

Motion Capture

Prior to data collection, the motion capture system was dynamically calibrated using a calibration wand (model CW-500) according to the manufacturer's recommendations. Using double-sided tape, twenty-seven spherical, reflective markers (14 mm diameter) were placed on the participant according to a modified Rizzoli full-body model (OptiTrack). Markers were placed on the skin or clothing at the following locations bilaterally (Figure 9): acromion process, humeral shaft, medial and lateral humeral epicondyle, anterior superior iliac spine (ASIS), femoral shaft, medial and lateral femoral condyle, tibial shaft, medial and lateral malleoli, proximal phalanx of second toe, and posterior calcaneus. A solitary marker was also placed on the superior sacrum (S1).

To properly calibrate the skeleton model, participants stood in a T-pose in the center of the data collection area for approximately 5 sec (OptiTrack). Once the model calibration was completed, participants performed their maximal effort throws with the turbo javelin. A oneminute rest was required between each throw (Kleeman, 2007). If there was missing data for either the right or left acromion or ASIS markers, additional trials were performed.

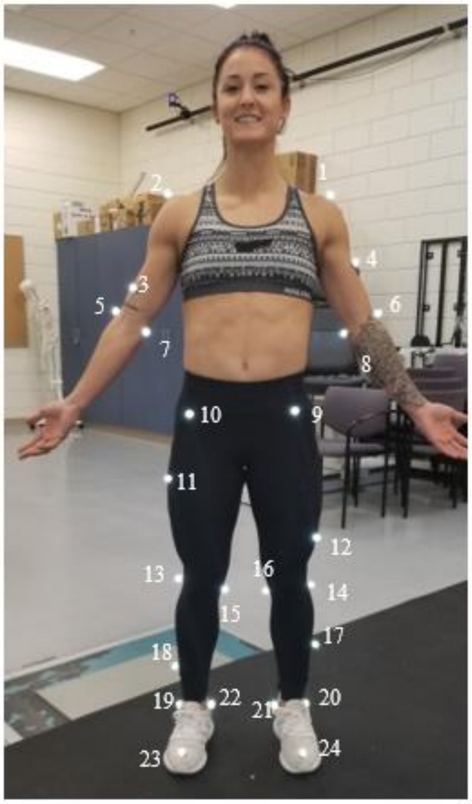

Figure 9. Placement of reflective markers for the skeletal model. Note markers 25 (L calcaneus) 26 (R calcaneus), and 27 (Sacrum 1) cannot be seen in this image.

Data Analysis

All markers coordinate missing data were filled either using a pattern-based setting in Optitrack. The coordinate data were exported to Visual 3D motion analysis software for further analysis. Data in Visual 3D were smoothed using a 7 Hz, low-pass Butterworth filter (McNitt-Gray, 1990). Motion data were analyzed for the throwing phase, defined by the events of initial drive foot contact and turbo javelin release. Hip-shoulder separation (θHSS) was calculated as the angle between the line pointing from the right hip joint center (RHJ) to the left hip joint center (LHJ) and the line pointing from the right shoulder joint center (RSH) to the left shoulder joint center (LSH) (Figure 10). A positive value for hip-shoulder separation angle indicated that the right hip was leading the right shoulder during the throw (Leigh, 2012). The difference in time at maximal resultant velocity of the drive hip and throwing shoulder joint centers were used to indicate separation timing.

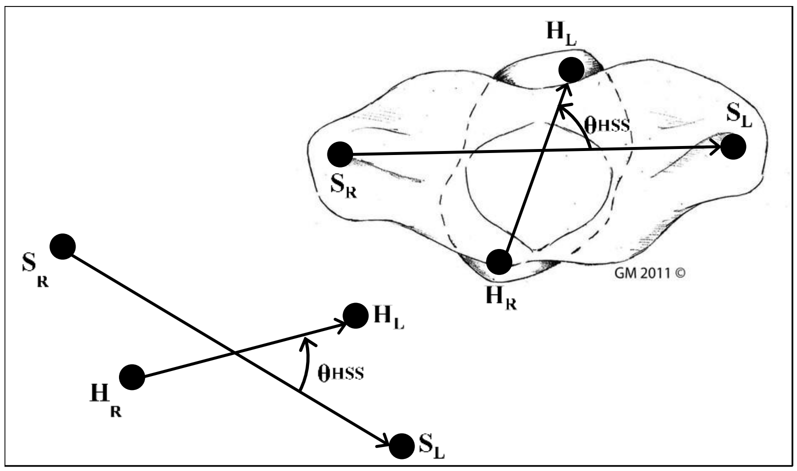

Figure 10. Hip-Shoulder Separation © Gary Mant (Leigh, 2012)

Statistical Analysis

Preliminary analyses were conducted to test for outliers and normality (Shapiro-Wilks test). Data are presented as means and standard deviations for all variables. The hip-shoulder separation maximum angle (HSSA) as well as the timing difference of hip vs shoulder maximal velocity (PVAC-PVASIS) were correlated with level of experience in years using Spearman correlation. Spearman's correlation was used due to the small sample size. All data were analyzed in SPSS v25.0 (IBM Corporation, Armonk, NY) with an alpha level set at $p < 0.05$.

Chapter 4. Results

Ten female javelin throwers were initially recruited from the greater Spokane area, however, only eight throwers participated in the study before face-to-face restrictions on data collection were put in place due to the COVD-19 pandemic. Four participants were high school athletes and four were collegiate athletes. All participants were right-hand throwers and had no private coaching experience prior to participating in this study. Four participants performed a 5-step approach while the other four utilized a 7-step approach (steps indicate the number of foot touches taken during the throw from start to release. Refer to Table 1 for group descriptive statistics and Table 2 for information about individual participants' level of experience, education level, and performance records.

Table 1
Participant Descriptive Statistics

Variables	*M*	*Max*	*Min*	*SD*
Age (yrs)	18.5	22.0	14.0	2.8
Height (m)	1.7	1.8	1.5	0.07
Weight (kg)	65.2	68.0	52.6	6.1
EXP*	3.3	6.0	1.0	1.8
Personal record throw (m)	33.7	45.9	19.8	9.5

**Note:* Years of Experience (EXP) indicates the number of years the athlete has competitively thrown the javelin.

Table 2
Participants' Level of Experience, Education Level, and Performance Records

Participants	High school/College	EXP	PR*(m)
1	H	1	37.62
2	C	6	33.76
3	C	4	45.89
4	H	1	19.84
5	C	5	42.67
6	H	2	26.52
7	C	4	39.80
8	H	3	23.292

**Note:* Personal Record (PR) indicates the farthest distance (m) the athlete has competitively thrown the javelin during a sanctioned competition. Years of Experience (EXP) indicates the number of years the athlete has competitively thrown the javelin.

Reliability

Reliability tests were conducted for each variable across all three trials using Cronbach's alpha. One-way ANOVAs were also run to assess for significant differences across trials. The variables assessed for reliability were hip-shoulder separation angle (HSSA), peak velocity of the right acromion (PVAC), peak velocity of right ASIS (PVASIS), and the difference in time between peak velocity of the right acromion and the right ASIS (PVAC-PVASIS). Missing HSSA data was found for one participant; thus, reliability was conducted on the remaining seven participants. Additionally, for PVAC-PVASIS one participant's PVAC occurred prior to PVASIS, resulting in a Cronbach's alpha of -0.130. Therefore, we removed this trial for PVAC-PVASIS, leaving us with 6 participants for the assessment of reliability for this variable. Table 3 displays the reliability (Cronbach's alpha) and the ANOVA (*p*) results for the four variables of the 6 participants assessed.

Table 3
Reliability Across Repeated Trial

Variables	Cronbach's' α	*p**
HSSA	0.88	0.31
PVASIS	0.90	0.98
PVAC	0.78	0.69
PVAC-PVASIS	0.75	0.12

**Note*: *p* value is the significance of the ANOVA

Based upon our reliability results, Cronbach's alpha increased for all four variables as well as resulted in a non-significant ANOVAs' *p* value with the removal of trial one. A non-significant *p* value indicated that removal of trial one would result in no significant differences between trial two and trial three performances. A higher Cronbach's alpha indicated that the data set had a high level of internal consistency. After removing trial one data for all variables, trial two and three were averaged to determine the values to be used in further analyses. A peak value for HSSA during the throwing phase for the third trial of one participant was not discernable, therefore we deemed that trial as inconclusive and used only trial two for this participant. After removal of trial one for all participants, Cronbach's alpha was improved and no variables had significant ANOVAs across trials (HSSA and PVASIS, $\alpha = 0.934$, $p = 0.310$ and $\alpha = 0.976$, $p = 0.216$ respectively). Trial one results could have been influenced by learning (Franceschini, Terzini, & Zanetti, 2017). A learning effect is a performance improvement produced by repetition over time. During the first couple of trials rapid improvement is seen more commonly. After multiple trials diminishing improvements are seen followed by a plateau (Franceschini et al., 2017). Since this was a novel laboratory environment for the participants, it was not unexpected that the first performance was different from the other two trials.

Normality

All variables met the assumption of normality, as assessed by the Shaprio-Wilks test (p = 0.18 (HSSA), p = 0.454 (PVASIS), p = 0.163 (PVAC), p = 0.262 (PVAC-PVASIS). Table 4 describes the descriptive statistics of the averages for trials two and three trials for all eight participants minus the removal of peak HSSA of trial three for one participant as its data was deemed inconclusive.

Table 4
Descriptive Statistics of Outcome Variables

Variables	*M*	*Max*	*Min*	*SD*
HSSA (degrees)	38.06	50.21	19.06	11.91
PVASIS (m/s)	3.87	4.82	2.78	0.73
PVAC (m/s)	4.74	6.16	3.32	1.14
PVAC-PVASIS (s)	0.11	0.16	0.02	0.04

Correlation

Spearman correlations were conducted to identify relationships between the following variables: age, years of experience (EXP), PVASIS, PVAC, PVAC-PVASIS, and HSSA. The Spearman correlation was deemed appropriate with these data due to the exploratory nature of the study and the small sample size. Pearson correlations with small sample sizes are more likely to be unreliable and produce correlation coefficients that can be either larger or smaller than the true population coefficient value. In addition, scatterplots of the variables demonstrated some potentially non-linear relationships. Pearson' coefficient would have underestimated the true strength of the relationship between our variables of interest. Refer to Table 5 for the Spearman correlation coefficient of each variable. Significant and high correlations were found between age and PVAC (r_s = 0.762, p = 0.028), PVASIS and PVAC (r_s = 0.714, p = 0.047), and age and EXP (r_s = .723, p = 0.043). All other variables were non-significant. A high degree, positive Spearman correlation indicates that there is a monotonic relationship between the two variables. When one variable increases or decreases so does the other but not always at the same rate. This means that when age increases so does peak velocity of the right acromion. In addition, when peak velocity of the right ASIS increase so do peak velocity of the right acromion during the throwing phase or the javelin throw.

Table 5
Spearman Correlation Coefficient

Variables	1	2	3	4	5	6
1.Age						
2.Years' Experience	**0.723***					
3.HSSA	0.429	0.072				
4.PVASIS	-0.357	-0.253	-0.452			
5.PVAC	**-0.762***	-0.289	-0.690	**0.714***		
6.PVAC-PVASIS	0.095	0.048	0.476	0.000	-0.333	

Note: Coefficients in bold and have an * are significant (p < 0.05).

Chapter 5. Discussion

The purpose of this study was to determine if there is a significant relationship between athlete level of experience and hip-shoulder separation angle (HSSA) and timing of peak velocities between the throwing shoulder and the drive hip (PVAC-PVASIS) during the throwing phase in the javelin throw. Participants consisted of four female high school athletes and four female collegiate athletes. There were no significant relationships between years of competitive javelin experience and the timing and degree of hip-shoulder separation in high school and collegiate throwers. Some possible reasons we did not find significance in our study could be participants lack of throwing experience.

Our study was based upon Leighs' (2012) and Ferdinand and colleagues (2013) studies. When comparing both studies to our results, one possible reason why we did not find a significant relationship among our variables of interest (HSSA, level of experience, and PVAC-PVASIS) may be that our participants were high school and collegiate throwers. As compared to Leigh and Ferdinands participants, which were elite throwers and professional bowlers, respectively. Elite throwers are less likely to make technical errors and are more consistent with their technique for each throw. Conversely, novice throwers are more likely to make technical errors and be less consistent in their technique (Mecklenburg, 1990). If technique is not consistent, HSSA could vary drastically between each throw. This could have been a reason why we did not find any significant results between HSSA and level of experience. Another possible reason is because our study did not compare HSSA to a performance variable. Leigh's study examined how a javelin thrower's technique effects release variables that determine performance. HSSA was one of multiple variables examined to see if it had an effect on release variables. Leigh analyzed HSSA at specific times during the throwing phase as compared to our study which looked for peak HSSA during the throwing phase. Ferdinands and colleagues' study peak HSSA was one of many kinematic variables assessed to investigate the relationship with release speed of the ball. Release speed in the javelin throw is also a performance variable since athletes with greater release speed generally have farther throws. Ferdinands study also looked at proximal-to-distal segment sequencing in terms of kinetic energy (KE) and SSC. With regard to KE, our study looked at the time difference between PVAC and PVASIS but not the magnitude of each velocity and their summation between each segment at release. This could be a possible reason why we did not find significant difference between PVAC-PVASIS and level of experience.

While no significant correlations were found among our variables of interest there were variables there were other interesting correlations that we found to be significant. Significant high correlations were found between age and level of experience ($r = 0.723$, $p = 0.043$) as well as age and PR ($r = 0.738$, $p = 0.037$), indicating that older athletes had more experience and better performance. The oldest athletes in this study were the collegiate athletes (20-22 yrs.) and had an average level of experience of 4.75 yrs. They also had the greatest average PR distance of 40.53 m (132ft 11in). An increase in PR distance may be due to an improvement in technical skill, or an increase in muscle strength. One of the most important markers of sport performance is muscular strength (Chaabene, Tabben, Mkaouer, Franchini, Negra, & Hammami, 2015; Davis, Wittekind, & Beneke, 2013). According to Gorostiaga and colleagues (2005), and Marques and colleague (2006) studies, an increase in strength improves muscle contraction rate and increases the amount of force that is applied during the throw. In Aka's 2020 study, he agrees that a throwers' shoulder muscular strength has a significant effect on the throwing distance. In Gorostiaga and colleagues' 2004 study, they found when comparing elite and amateur handball players that elite handball players had 16-22% higher maximal strength and power of the upper extremity muscles during half squat and bench press. They also found in their study that elite handball athletes throwing velocities were 8% greater ($p < 0.01$) than the amateur athletes. These findings agree with Mikkelsen and colleagues' (1976) findings that there is a significant correlation between throwing velocity and type II muscle fibers, suggesting that athletes with faster throwing velocities are better at quickly activating fast twitch muscle of the upper extremity. As mentioned earlier, release velocity has been shown to be the primary factor that determines the distance of the throw. Therefore, having greater muscular strength will increase release velocity and the distance of the throw. They then infer that ball velocity of elite athletes depends more on upper and lower extremity power output capacity than amateur athletes. Gorostiaga and colleagues (2005) suggest then that because elite athletes depend more on upper and lower extremity power output to achieve a high release velocity that their ability to perform the technical skill of quickly extending at the hip, and knee joints prior to trunk rotation and upper extremity activation contributes also to achieving a high release velocity (Elliott, Grove, & Gibson, 1986; Fleck, Smith, Craib, & Mitchell, 1992; Toyoshima, Hoshikawa, Miyashita, & Oguria, 1974). Regarding an improvement in technical skill, Gorostiaga and colleagues (2005) also found significant relationship between elite handball athletes throwing velocity during a 3-step run approach as compared to a standing throw. The faster the approach speed in the 3-step, the greater the release velocity the athletes produced. This suggest that a running approach is related to the ability to move low loads at maximal velocity with the upper body segment (Joris, Van Muyen, Van Ingen Schenau, & Kemper, 1985). The absence of a significant relationship between muscle power output and a 3-step running approach in the amateur athletes could be related to less skill in throwing technique (Gorostiaga, Granados, Ibáñez, & Izquierdo, 2005).

Therefore, arm throwing efficiency depends on muscle strength and power, but also on throwing technique and the athlete's ability to coordinate complex fast sequential actions of body segments starting at the legs, through the trunk and into the upper extremity (Joris et al., 1985; Muijtjen, Joris, Kemper, & Ingen Schenau Van, (1991). Based on our results as well as those in the literature, the primary reason we did not find expected relationships may be because of lack of variability of participants level of experience. Thereby causing their throwing mechanics and muscular strength to be not as developed as elite throwers.

In this study we did not measure release velocity directly, however PVAC is related to release velocity. Release velocity is the main factor that effects the distance of the throw (Best et al., 1993). To achieve a high release velocity this requires fast limb motions to accelerate the javelin (Bartlett, 1988; Terauds, 1978). Energy is transferred upward from the legs to the trunk, to the shoulder, to the hand, and into the javelin at release. Kinetic energy and power are both directly proportional to velocity: $KE = 1/2\ m\ v^2$ and $P=F(\Delta V/\Delta t)$. The greater the velocity of each segment during the throwing phase, the more energy that is transferred up into the javelin allowing a higher power output, resulting in a greater release velocity. Regarding level of experience Bartlett and colleagues (1996) stated that throwers with more experience will have greater release velocities compared to novice throwers (Bartlett et al., 1996). The results from our study support Bartlett's (1996) study. The collegiate throwers with an average of 4.75 years of experience had a mean PVAC of 5.28 m/s. Compared to the high school throwers, who had an average of 1.75 years of experience had a mean PVAC 4.22 m/s.

There was a high significant correlation between PVASIS and PVAC (r = 0.714, p = 0.047). When the PVASIS increases, so does PVAC. There was also a high significant correlation between age and average peak velocity of the right ASIS (r = 0.762, p = 0.028). As athletes increase in age, the utilization of the right hip increases during the throwing phase, generating a greater peak hip velocity. The energy from the drive hip transfers up into the trunk and into the throwing shoulder, thereby increasing the PVAC. Increasing the velocity of the throwing shoulder (AC) will then transfer energy into the javelin increasing release velocity. Results from our study also support Ferdinands and colleagues (2012) who showed that kinetic energy (KE) transfers up through the body (proximal-to-distal) in throwing. If you refer to Table 7 below, three quarters of participants had an increase in PVAC from PVASIS. When peak velocity of the right ASIS occurs prior to peak velocity of the right acromion, then the drive hip is in motion prior to the shoulder during the throwing phase. The three oldest participants in this study had an average of 4.43 m/s for their PVASIS, an average of 5.78 m/s for their PVAC, and an average PR of 42.79 m. Participants in this study with a greater PVAC also reported greater PR. This supports Bartlett (1988), Terauds (1978), and Best (1993) statement that a faster moving limb generates a higher release velocity thereby improving performance. When peak velocity of the right ASIS occurs after peak velocity of the right acromion, this means that the throwing shoulder is leading the hips during the throwing phase. This then would create a negative HSSA. Having PVAC occur prior to PVASIS indicates that the athlete was not able to utilize the power generated by their lower body in the throw. This then puts a lot of stress on their shoulder to provide power for the throw. If this technique is continued, it will cause increased stress to the shoulder joint tissues and can result in possible injury (Howenstein et al., 2019; Sgroi et al., 2015; Wilk et al., 2000; Seroyer et al., 2010).

Table 7
Participants' Individual Performance Variables

Participant	HSSA (deg)	PVASIS(m/s)	PVAC(m/s)	PVAC-PVASIS(s)	PR (m)
1	37.22	4.52	5.76	0.13	37.62
2	22.32	3.32	3.77	0.12	33.76
3	50.21	3.74	6.16	0.13	45.99
4	19.06	2.78	3.32	0.02	19.84
5	29.48	4.82	3.63	0.09	42.67
6	47.24	3.63	3.63	0.13	26.52
7	48.49	4.73	5.78	0.08	39.80
8	44.23	3.45	4.16	0.16	23.29

A decrease in HSSA during the throwing phase is expected with the rotation of the body from sideward facing to forward facing the toe board at release. Along with the shoulder's transitioning from max external rotation to internal rotation. Leigh's, 2012 findings display this phenomenon of the decrease in HSSA from RFC (right foot contact), to left foot contact (LFC), to release. Leigh did not report HSSA at RFC, LFC, and release for every participant because all throwers yielded similar results, however, by looking at three different participants data HSSA from RFC to LFC resultantly decreased: HSSA at RFC = 43˚, SD = 11, at LFC = 22˚, SD = 8, and at release = 7˚, SD = 12. Results from our current study agree with Leigh's findings: HSSA at RFC 35.65˚, SD = 9.58, at LFC 29.13˚, SD = 15.64, and at release = 1.94˚, SD = 14.79. This indicates that during the throwing phases all participants were rotating from a side facing position to a forward facing position from RFC to release. By doing so they are utilizing the SCC during the throw to increase KE from the spiral rotation from right foot contact to release. However, the degree of KE being produced and the efficiency of their SCC we cannot determine.

According to Portus and colleagues (2004), they found that the timing of maximum hip-shoulder separation angle after front foot contact was moderately correlated with implement speed (*r* = 0.340). The earlier the HSSA occurs during the throwing phase the greater the pre-stretching of muscles, leading to a more powerful concentric action of the muscles and greater power production (Ferdinands et. al, 2013 & Kreighbaum & Barthels 1985). Our results agree with Ferdinand (2013) and Kreighbaum (1985) statement. In our study peak HSSA was identified as the peak that occurred between drive foot contact after the impulse drive and release. Five participants had their actual peak HSSA occurred prior to drive foot contact for both trial two and three. The majority of the collegiate athletes peak HSSA occurred during the single support phase (between drive foot contact and block foot contact) and the majority of high school athletes peak HSSA occurred during the bow-tension phase (between block foot contact and when the hips where parallel in the throw). Athletes with peak HSSA occurring in the single support phase had a greater PVAC and farther PR distances. The participant with the greatest HSSA (50.95° at $t = 0.683$ s) occurred in the single support phase (drive foot contact time $t = 0.533$, block foot contact time $t = 0.742$ s), along with the fastest PVAC (6.16 m/s), and the farthest PR (45.9 m). A greater HSSA may have increased muscle pre-stretch resulting in a higher velocity of the shoulder. This would lead to an increase in kinetic energy, an increase in power resulting in a high release velocity, improving performance.

Limitations

An important limitation that came about during the conduction of this study was a lack of participants. This was due to the outbreak of the COVID-19 pandemic, which occurred during data collection. Face-to-face data collection was suspended by the university until further notice after data had been collected on only 8 participants. Small sample size also had an effect on the statistical analysis. Correlations with small sample sizes are more unreliable, are more likely to obtain a small correlation coefficient (*r*) and fluctuate more from the “true” population *r* (Hole, 2018). A small *r* indicates that there is a weak relationship between the two variables. Because of small sample size results could be misleading to think that there is no relationship between two variables. Our original sample size of 13 gave us a power of 0.80. With a sample size of 8 our post-hoc power was 0.49. With a lower power due to small sample size, the probability of making a Type 2 error is increased. There is a possibility that a high correlation and strong relationship could be found between level of experience, HSSA and PVAC-PVASIS with a greater sample size. A small sample size also decreases reliability, which decreases how accurate *r* is for level of experience, HSSA and PVAC-PVASIS. Future studies on this population of javelin throwers should include a larger sample size, approaching or exceeding that estimated based on statistical power analyses.

The duration of rest between trials was not consistent across participants and trials. After each trial, the researcher would confirm that the RASIS and RAC markers were captured by the cameras. For some participants, this duration was longer. In addition, the data collection software ‘crashed’ at least once on approximately half of all participants, causing delays between trials. Multiple phone calls to company support did not yield a consistent nor timely solution to this problem.

The marker set used for calculating trunk and pelvis separation (HSSA) was also a potential limitation, as it was not the optimal marker set for this variable. According to Brown and colleagues (2013), there are three methods to find the rotation of the pelvis and the rotation of the shoulder. Our study utilized a method where pelvis (right and left ASIS) and shoulder (right and left acromion) orientations were calculated separately relative to the transverse plane as projected planar angles. Angles were subtracted from each other to obtain HSSA. Motion of the thorax or trunk were not tracked in this study. The problem with orientation angles (rotation, bend, and side bend) is that different rotation sequences will generate different sets of orientation angles for the same thorax position (Kwon, 2018). A second method to calculate HSSA analyzes the angle of orientation individually. Therefore, a different outcome angle could have been collected depending on the order of segmental rotation during the throw. Athletes who are not consistent with their throwing technique, such as novice throwers, could have had one trial where their shoulders rotated prior to the hips and another trial where the hips rotated prior to the shoulder during the throwing phase. Each trial would produce a shoulder and hip orientation angle but because of the segmental sequence, angles found could not be consistent, then producing inconsistent HSSA data for that athlete. A third and final method described by Brown and colleagues calculated the orientation of the thorax relative to the pelvis segment coordinate system, resulting in the Z component being rotated about the Z-axis for HSSA data. This method uses three markers placed at C7, T10, and L4 to define and track movements of the thorax. This method accounts for orientation of the pelvis relative to the thorax, better describing the interaction of the pelvis and the shoulders which are connected via the thorax. However, the model used in our current study did not include these marker locations, therefore this method could not be used to calculate HSSA. With angle orientation of the thorax being relative to the pelvis, the order of segmental rotation does not affect the outcome of the HSSA.

Collecting data in a lab versus field has its own limitations. While increasing internal validity, collecting data in a lab reduces external validity. Laboratory tests are useful for creating the “big picture” in a controlled environment with standardized protocols and allow the use of fixed equipment like a 3-D motion analysis system with fixed cameras. Field test are conducted in the playing environment, generally with less technical and precise equipment while the athlete performs the actual or simulated event or activity. Some activities, such as cycling and running, are easily transferred from the laboratory to the field. Other activities like the javelin throw are more difficult to simulate in the laboratory. Laboratory testing is oftentimes more reliable (or reproducible) because physiologic characteristics can be more precisely measured. Field test are conducted in real-world settings yielding results more to what would occur during a competition (Mendel & Cheatham 2008). Some participants reported that they did not throw with full effort because they did not feel comfortable throwing in the lab. With not performing a full effort throw, participants could have adjusted their technique including their HSSA and PVAC-PVASIS, thereby reducing the validity of these results.

During the study, three participants asked if they could wear their throwing shoes. Javelin throwing shoes have 11 metal spikes on the sole, with 4 located in the heel and 7 located at the forefoot for both right and left shoe. This allows the thrower to “stop” in the approach once the block foot has contacted the ground after the impulse drive. This aids in throwing technique allowing the whipping action to occur. Throwing shoes may also help to prevent injury from slipping. Not being able to wear their throwing shoes may have reduced the participants’ approach speed. This could have had an effect on their mechanics of their throw thereby effecting results. Javelin shoes were not worn during the study to prevent possible damage to the lab and is an established delimitation to our study.

Future Research

Future research should continue to look into throwing techniques of collegiate and high school level athletes. Throwing performance gradually improves throughout childhood and into early adolescent (Lorson, et al. 2013) along with coordination, balance, and muscular strength (Butterfield & Loovis, 1993). Older throwers are more likely to have learned the proper throwing mechanics compared to youth throwers. However, if proper throwing motor patterns were not developed at a young age, a bad habit or motor pattern has been developed. Motor patterns are more resistant to change once habbits have been established (Lorson et al., 2013). Motor parterns are devloped via motor learning, a process of aquiring the capcaity for skilled aciton(s) via an experince or practice. Motor learning produces a "relatively permanent" change to motor paterns with temporary gains that can be accuried during practice (Patil, 2018). If a bad throwing motor pattern has been established, it is unlikely then to change. Proper throwing mechanics of the javlein throw and knowledge of the kinetic chain should be learned when an athlete first begins to throw to prevent injury and to improve performance (Seroyer et al. 2010).

Future research should seek to identify variables that affect HSSA. One example would be to evaluate the stride length of the drive foot to block foot and its relationship to HSSA. According to Vassilosi and collegues (2013), stride length has an effect on efficiency of the throwing movement. Increasing throwing movement should also improve HSSA, therefor improving distance of the throw and performance. Also, according to Bielik, (1984) a smaller duration between right foot contact and release (throw duration) has been shown to increase the distance of the throw. How does throwing duration effect HSSA? Does a shorter duration increase HSSA, therfore increasing distance of the throw? Lastly, investigating how HSSA angle effects the KE caused by the SCC, does it increase PVASIS and PVAC? A greater stretch caused by a greater HSSA should produce more KE thereby increasing the velcoity of the right ASIS and right acromion.

Increasing the sample size of 12-18 participants could increase the probability of finding statistically significant results. Bartlett and colleagues (1996) found significant relationships between release parameters (releases speed and release angle) and distance thrown (n = 12, $p <$ 0.01), as did Vassilios and Iraklis (2013) between release velocity and distance thrown (n = 16, r

= .909, $p < .001$) and LeBlanc and Mooney (2004) between trunk angle and release angle (n = 18, $p < 0.025$).

Using a turbo javelin versus a 600g IAAF javelin as the throwing implement was a chosen delimitation of the study. Future studies should strive to utilize a 600g IAAF javelin to increase the external validity of the study. Future studies could be designed to investigate the influence of sex on HSSA, PVAC, and PVASIS in this population as well as the relationship between HSSA and release velocity.

Lastly, by adding markers to landmarks C7, T10, and L4. This would be utilizing Brown and colleagues (2013) method of analyzing the orientation of the thorax relative to the pelvis segment coordinate system to analyze HSSA. This will allow the researcher to see how the shoulders, the pelvis, and the trunk move individually but also as a unit. This will prevent the possibility of a different set of orientation angles from different rotation sequences (Kwon, 2018).

Summary

There were no significant results between level of experience and hip-shoulder separation angle and the difference in ASIS and AC peak velocities. Increasing the hip-shoulder separation angle and ASIS and AC peak velocities has been shown to increase the pre-stretch of the muscles providing a more powerful concentric contraction of the muscles resulting in a greater power production, increasing release velocity and performance. (Ferdinands et al., 2013 and Kreighbaum & Barthels, 1985). Future studies should continue to investigate throwing techniques of collegiate and high school athletes how technique affects hips shoulder separation angle and peak velocity of the acromion minus peak velocity of the anterior superior iliac spine (ASIS).

Appendix A

Throwing Questionnaire

The primary purpose of this questionnaire is to collect information about your experience in throwing the javelin. Please answer each question as completely as you can. If you have questions about any of the items in this questionnaire, please ask the investigator for clarification.

1) Birthdate (month/day/year): ________________________

2) Please circle the value that best describes your current level of education:

HS: 9th grade 10th grade 11th grade 12th grade(senior)
College: Freshman Sophomore Junior Senior

3) Name of your current educational institution:
____

4) Throwing arm (Check one box): ☐ Right ☐ Left

5) How many years of experience do you previously have prior to conduction of this study in the javelin throw? (Example: 1 season for high school outdoor track and field)

6) What is your personal record (PR) in the javelin throw? __________feet

___________inches

7) How many javelin coaches have had? Please include private and school-affiliated

coaches. ________________

8) Have you ever been privately coached in the javelin throw? ☐ Yes ☐ No

   a. If yes, for how long did you receive private coaching? _____ years_____months

9) What is the length of your full approach? (the number of steps running forward plus the number of sets of crossovers) ______________ feet or ________________ meters.

References

Aka, Hasan. (2020). The investigation of the relationship between throwers' isokinetic strength and throwing speed and distance in the athletics. *International Journal of Applied Exercise Physiology. 9*. 178-182.

Akbarshahi, M., Schache, A. G., Fernandez, J. W., Baker, R., Banks, S., & Pandy, M. G. (2010). Non-invasive assessment of soft-tissue artifact and its effect on knee joint kinematics during functional activity. *Journal of Biomechanics, 43*(7), 1292–1301.

Ariel, G. B., Pettito, R. C., Penny, M. A., & Terauds, J. (1980). Biomechanical analysis of the javelin throw. *Track & Field Quarterly Review, 80*(1), 9-17.

Bartlett, R., Müller, E., Raschner, C., Lindinger, S., & Jordan, C. (1995). Pressure distributions on the plantar surface of the foot during the javelin throw. *Journal of Applied Biomechanics, 11*(2), 163-176.

Bartlett, R., Müller, E., Lindinger, S., Brunner, F., & Morriss, C. (1996). Three-dimensional evaluation of the kinematic release parameters for javelin throwers of different skill levels. *Journal of Applied Biomechanics, 12*(1), 58-71.

Bartlett, R.M. & Best, R.J. (1988). The biomechanics of javelin throwing: A review. *Journal of Sports Science, 6,* 1-38

Best, R. J., Bartlett, R. M., & Morris, C. J. (1993). A three-dimensional analysis of javelin throwing technique. *Journal of Sports Sciences, 11*(4), 315-328.

Best, R. J., Bartlett, R. M. & Sawyer, R. A. (1995). Optimal javelin release. *Journal of Applied Biomechanics*, *11*, 371-394.

Bielik, E. (1986). Relationships of release velocity to key delivery phase variables of highly skilled decathletes in the javelin event. (Master's thesis). Available from University of Kansas Libraries.

Blackburn, J. C. (2019). *2019 USATF competition rules*. Indianapolis, Indiana: USA Track & Field.

Brown, S.J., Selbie, S.W., & Wallace, E.S. (2013). The X-factor: An evaluation of common methods used to analyze major inter-segment kinematics during the golf swing. *Journal of Sport Science, 31*(11), 1156-1163

Butterfield, S. A., & Loovis, M. (1993). Influence of age, sex, balance, and sport participation on development of throwing by children in grades k-8. *Perceptual and Motor Skills 76*, 459-464.

Chaabene H, Tabben M, Mkaouer B, Franchini E, Negra Y, Hammami M. (2015). Amateur boxing: physical and physiological attributes. *Sports Med*, *45*(3): 337-52.

Davis, P. Wittekind, A., Beneke, R. (2013). Amateur boxing: activity profile of winners and losers. *International Journal of Sports Physiology Performance 8*(1): 84-91.

Della Croce, U., Leardini, A., Chiari, L., & Cappozzo, A. (2005) Human movement analysis using stereophotogrammetry Part 4. Assessment of anatomical landmark misplacement and its effects on joint kinematics. *Gait & Posture, 21*, 226-237

Elliott, B., Grove, R., & Gibson, B. (1986). Timing of the lower limb drive and throwing limb movement in baseball pitching. *International Journal of Sports Biomechanics*, *4*, 59-67.

Feltner, M. E. (1989). Three-dimensional interactions in a two-segment kinetic chain. Part II: Application to the throwing arm in baseball pitching. *International Journal of Sport Biomechanics*, *5*, 420-450.

Ferdinands, R., Kersting, U. G., & Marshall, R. N. (2013). Kinematic and kinetic energy analysis of segmental sequencing in cricket fast bowling. *Sports Technology, 6*(1) 10-21.

Fleck, S., Smith, S., Craib, M., & Mitchell, M. (1992). Upper extremity isokinetic torque and throwing velocity team handball. *Journal of Applied Sport Science, 6*, 120-124.

Franceschini, G., Terzini, M., & Zanetti, E. M. (2017). Learning curves of elite car racers. *International Journal of Sports Science & Coaching*, 12(2), 245–251.

Frikha, M., Chaâri, N., Mezghanni, & Souissi, N. (2016). Influence of warm-up duration and recovery interval prior to exercise on anaerobic performance. *Biology of Sport*, *33*(4), 361-366.

Gorostiaga, E., Granados, C., Ibáñez, J., & Izquierdo, M. (2005). Differences in physical fitness and throwing velocity among elite and amateur male handball players. *International Journal of Sports Medicine*, *26*(3), 225-32 .

Gorski, J. P. (1982). Development of the soft-step javelin technique. *Coaching Clinic, 20*(3), 27-32.

Gregor, R. J., & Pink, M. (1985). Biomechanical analysis of a world record javelin throw: A case study. *International Journal of Sport Biomechanics, 1*(1), 73-77.

Hay, J. G. (1973). Biomechanics of sports techniques. Englewood Cliffs, N.J.; Prentice-Hall.

Henning, L., Plummer, H., & Oliver, G. D. (2012). Comparison of scapular muscle activations during three overhead throwing exercises. *International Journal of Sports Physical Therapy, 11* (1), 108-114.

Hole, G. (2018). Eight things you need to know about interpreting correlations. *Research Skills One, Correlation interpretation, 1,* 1-9

Howard, M. M. (2019). Turbo javelin throwing information. Retrieved from https://www.sportsrec.com/281717-turbo-javelin-throwing-information.html.

Howenstein, J., Kipp, K., & Sabick, M. B. (2018). Energy flow analysis to investigate youth pitching velocity and efficiency. *Medicine & Science in Sports & Exercise, 51*(3), 523-531.

Jobe, C. M., & Coen, M. J. (2000). Evaluation of impingement syndromes in the overhead-throwing athlete. *Journal of Athletic Training, 35*(3), 293.

Joris, H., Van Muyen, A., Van Ingen Schenau, G., & Kemper, H. (1985). Force velocity and energy flow during the overarm throw in female handball players. *Journal of Biomechanics, 18,* 409-414.

Kleeman, G. (2007). The Throwing Official's Manual. *USATF National Officials Monograph Series*, 1–36.

Knighton, A. (2017, November 17). How the Spear Transformed Warfare - From Ancient Times to The Age of Gunpowder. Retrieved from https://www.warhistoryonline.com/instant-articles/spear-transformed-warfare-m.html.

Komi, P. V., & Mero, A. (1985). Biomechanical analysis of Olympic javelin throwers. *International Journal of Sport Biomechanics, 1*(2), 139-150.

Kwon, Y.H., (2018). Thorax angles: A new method of calculation. *Dr. Kwons Golf Biomechanics,* 1-6.

Kreighbaum, E., & Barthels, K. M. (1995). *Biomechanics- A qualitative approach for studying human movements*. (4) Minneapolis, MI: Burgerss.

Lawler, P. (1993). The javelin throw - the past, present and future. *New Studies in Athletics, 8*(3), 15-23.

LeBlanc, M., & Mooney, R. G. (2004). Kinematic differences in elite-level American male and female javelin throwers. *Engineering of Sport 5,1* (1), 182-188.

Leigh, S. (2012). *The Influence of Technique on Throwing Performance and Injury Risk in Javelin Throwers* (Doctoral dissertation). Retrieved from https://cdr.lib.unc.edu/concern/dissertations/hh63sw92n

Leigh, S., Gross, M. T., Li, L., & Yu, B., (2008). The relationship between discus throwing performance and combination of selected technical parameters. *Sports Biomechanics, 7*(2), 173-193.

Liu, H., Leigh, S., & Yu, B. (2010). Sequences of upper and lower extremity motions in javelin throwing. *Journal of Sports Sciences, 28*(13), 1459-1467.

Liu, H., Leigh, S., & Yu, B. (2014). Comparison of sequence of trunk and arm motions between short and long official distance groups in javelin throwing. *Sports Biomechanics, 13*(1), 17-32.

Lorson, K. M., Stodden, D. F., Langendorfer, S. J., & Goodway, J. D. (2013). Age and gender differences in adolescent and adult overarm throwing. *Research Quarterly for Exercise and Sport, 84*, 239-244.

Lubans, D. R., Morgan, P. J., Cliff, D. P., Barnett, L. M., & Okely, A. D. (2010). Fundamental movement skills in children and adolescents. *Sports Medicine, 40*(12), 1019–1035.

Marques, M. & González-Badillo, J. (2006), In-season resistance training and detraining in professional team handball players. *Journal of Strength and Conditioning Research, 20*(3): 563-571.

Marshall, R. N., & Elliott, B. C. (2000). Long- axis rotation: The missing link in proximal-to distal segmental sequencing. *Journal of Sports Science, 18*, 247-254.

Maryniak, J., Ladyzynska-Kozdras, E., & Golinska, E. (2009). Mathematical modeling and numerical simulations of javelin throw. *Human Movement, 10*(1), 16-20.

Mecklenburg, M. (1990). Cinematographically study of parameters in the javelin throw. (unpublished masters project). Montana State University, Bozeman.

Mendel R.W., Cheatham C.C. (2008) Laboratory and Field Techniques for Measuring Performance. In: Antonio J., Kalman D., Stout J.R., Greenwood M., Willoughby D.S., Haff G.G. (eds.). Essentials of Sports Nutrition and Supplements. Humana Press.

Mero, A., Komi, P. V., Korjus, T., Navarro, E., & Gregor, R. J. (1994). Body segment contributions to javelin throwing during final thrust phases. *Journal of Applied Biomechanics*, *10*(2), 166–177.

Meron, A., & Saint-Phard, D. (2017). Track and field throwing sports: Injuries and prevention. *Current Sports Medicine Reports, 16*(6), 391–396.

McGill, K. (2010). The right leg in the javelin throw. *Track Coach,* (191), 6089–6094.

Mikkelsen, F., & Olsen, M. (1976). *Handball* (82-84). Trygg-Hansa: Stockholm.

Miller, D. I., & Munro, L. F. (1983). Javelin position and velocity patterns during final foot plant preceding release. *Journal of Human Movement Studies, 9*(1), 1-20.

Moon, F. C. (2007). *The machines of Leonardo da Vinci and Franz Reuleaux: kinematics of machines from the Renaissance to the 20th century* (Vol. 2). Dordrecht: Springer

Muijtjen, A., Joris, H., Kemper, H., & Ingen Schenau Van, G. (1991). Throwing practice with different ball weights: effects on throwing velocity and muscle strength in field handball players. *Journal of Sports Training Medicine Rehabilitation, 2*, 103-113.

Murakami, M., Tanabe, S., Shikawa, M., Isolehto, J., Komi, P. V., & Ilto, A. (2006). Biomechanical analysis of the javelin at the 2005 IAAF World Championships in Athletics. *IAAF*, *21*(2), 67–80.

NCAA. (2019). RULE 1: Construction of facilities. Retrieved from https://www.ncaa.org/sites/default/files/Field Diagram Track and Field.pdf.

Oliver, G. D., Washington, J. K., Barfield, J. W., Gascon, S. S., & Gilmer, G. (2018). Quantitative analysis of proximal and distal kinetic chain musculature during dynamic exercises. *Journal of Strength & Conditioning Research. 32*(6), 1545-1553.

Patil, V. V. (2018). Theories of motor learning. Slide Share: Health & Medicine. Retreived from https://www.slideshare.net/Vimscopt/theories-of-motor-learning

Portus, M. R., Mason, B. R., Elliott, B. C., Pfitzner, M. C., & Done, R. P. (2004). Technique factors related to ball release speed and trunk injuries in high performance cricket fast bowlers. *Sports Biomechanics, 3*(2), 263-284.

IAAF. (2010) Javelin throw. Retrieved from https://www.iaaf.org/disciplines/throws/javelin-throw.

Rácz, K., Pálya, Z., Takács, M., Nagymate, G., & Kiss, R. (2018). Investigation of calibration accuracy of anatomical landmarks in an optical motion analysis method. *Biomechanica Hungrica,11*.

Rosenbaum, M. (2017). Olympic javelin rules. Retrieved from https://www.liveabout.com/olympic-javelin-throw-rules-3258886.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C., Nicholson, G. P., & Romeo, A. A. (2010). The kinetic chain in overhand pitching: Its potential role for performance enhancement and injury prevention. *Sports Health: A Multidisciplinary Approach, 2*(2), 135-146.

Sgroi, T., Chalmers, P. N., Riff, A. J., Lesniak, M., Sayegh, E.T., Wimmer, M. A., Verma, N. N., Cole, B. J., & Romeo, A. A. (2015). Predictors of throwing velocity in youth and adolescent pitchers. *Journal of Shoulder and Elbow Surgery*, 1-7.

Sweet, W. E. (1987). *Sport and recreation in ancient Greece: A sourcebook with translations.* New York: Oxford University Press.

Terauds, J. (1978) Computerized biomechanical analysis of selected javelin throwers at the 1976 Montreal Olympiad. *Track and Field Quarterly Review*, 78(1),29-31.

Terauds, J. (1984). Biomechanics of Tom Petranoff's javelin throw. *Track and Field Quarterly Review, 48*(1), 30-32.

Tidow, G. (1996). Model technique analysis sheets - part X: The javelin throw. *New Studies in Athletics, 11*(1), 45-62.

Toyoshima, S., Hoshikawa, T., Miyashita, M., & Oguria, T. (1974). *Contribution of the body parts to throwing performance.* Baltimore, MD: University Park (169-174)

UCSF Clinical & Translational Science Institute, June 12, 2019, Retrieved from https://data.ucsf.edu/research/sample-size

Vassilios, P., & Iraklis, K. A. (2013). Kinematics of the delivery phase and release parameters of top female javelin throwers. *Kinesiologia Slovenica, 19*(1), 32-43.

Washington Interscholastic Activities Association (WIAA). (2019). Retrieved from https://www.nfhsnetwork.com/associations/wiaa-wa.

Weber, A. E., Kontaxis, A., O'Brien, S. J., & Bedi, A. (2014). The biomechanics of throwing: Simplified and cogent. *Sports Medicine & Arthroscopy Review, 22*(2), 72-79.

Whiting, W. C., Gregor, R. J., & Halushka, M. (1991) Body segment and release parameter contribution to new-rules javelin throwing. *International Journal of Sport Biomechanics,* (7), 111-124.

Wilk, K. E., Meister, K., Fleisig, G., & Andrews, J. R. (2000). Biomechanics of the overhead throwing motion. *Sports Medicine & Arthroscopy Review, 8*(2), 124-134.

Young, M. (2008) Preparing for the specific neuromuscular and biomechanical demand of the javelin throw. Human Performance Consulting, 1-12. Retrieved from http://www.nationalthrowscoachesassociation.com/forms/javelinthrowbiomechanics.pdf

Zarnowski, F. (2013). *The pentathlon of the ancient world*. McFarland.

Zernicke, R. F., & Roberts, E. M. (1976). Human lower extremity kinetic relationships during systematic variations in resultant limb velocity. In P. V. Komi (Ed.), *Biomechanics V-B* (0-25). Baltimore, MD: University Park Press.

Vita

Author: Samantha Baker

Place of Birth: Spokane, Washington

Undergraduate Schools Attended: Eastern Washington University

Degree Awarded: Bachelors of Science, Exercise Science, 2017, Eastern Washington University

Honors and Awards: Gradate Assistantship, Fitness Center Supervisor, 2019-2020, Eastern Washington University

Graduated Magna Cum Laude, Eastern Washington University, 2017

All-Conference Big Sky Outdoor Track and Field, 2016, Eastern Washington University

All-Conference Big Sky Outdoor Track and Field, 2017, Eastern Washington University

Female Scholar Athlete of the month- April, 2017, Eastern Washington University

All-Academic NCAA Women's Track and Field, 2015, Eastern Washington University

All-Academic NCAA Women's Track and Field, 2017, Eastern Washington University

Previous Research: Post Exercise Blood Lactate Recovery: Pneumatic Leg Compression VS Ice Submersion, Presented at 2017 Exercise Science Research Symposium, Eastern Washington University

Acute Cardiovascular Responses to Ice Submersion VS Pneumatic Leg Compression for Recovery Post Resistance Training Presented at 2017 Exercise Science Research Symposium, Eastern Washington University

Effect of Static Hip Flexor Stretching on Standing Pelvic Tilt and Lumbar Lordosis, Presented at 2019 EWU Student Research& Creative Works Symposium, & ACSM Northwest 2020, Boise ID, & 2020 Eastern Washington University CHSPH Research Day

Professional Experience: Student Athlete, Track and Field- Javelin throw, 2013-2017, Eastern Washington University

Teaching Assistant, Mechanical Kinesiology, 2019-2020, Eastern Washington University

Private Javelin Coach, 2017-2020, Spokane Washington

Coach, Supertots Sports Academy, 2018, Spokane Washington

Assistant Javelin Coach, Ironwood Throws Camp, 2020-Present, Rathdrum Idaho

Javelin Coach, EWU Track & Field, 2019- Present, Eastern Washington University