Asymmetric Lower Body Force Output While Performing a Barbell Back Squat in NCAA Division II Athletes

By

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A thesis prepared by Uchenna C. Ogbonnaya

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Abstract

Symmetry exists in the universe, in nature, and within the human body. However, over time the body develops an asymmetrical nature. For example, the body develops differences in limb length, favors handedness, and may have unequal force exertion (Newton et al., 2006). Asymmetrical force output potentially, depending on the severity, can be a major problem for athletes and strength and conditioning (SC) coaches because it can cause athletes to be categorized as "high risk" for injury. To date, there is a limited research on the variables causing asymmetry in the force output in athletes. **Purpose:** The purpose of this study was to determine if there was a correlation between lower body force output asymmetry and positioning on the field in NCAA Division II collegiate athletes by measuring force output using symmetry angle (SA) while performing a barbell back squat (BS). **Methods:** Fifty-three NCAA Division II athletes: baseball (BB) = 8; softball (SB) = 13; men's soccer (MS) = 11; women's soccer (WS) = 11; women's volleyball (VB) = 10 volunteered for the study. The participants of this study had a mean age of 20.19 ± 1.25 yr., height of 169.58 ± 9.28 cm, weight of 70.52 ± 10.91 kg, time played in position of 9.06 ± 4.48 yr., experience lifting weight of 5.16 ± 2.46 yr., and symmetry angle of -0.36 ± 2.90 percent. Each participant performed a five-minute bike warm-up and one warm-up set of the BS before performing the test of three sets of one rep at 70% of their 1RM. The participants performed the test while standing on two force plates that measure local vertical peak force (N). **Results:** An independent t-test showed that there was a significant difference in mean values for SA between men and women ($p = 0.01$). An ANOVA showed that there also was significant difference in the mean values between sports ($p = 0.03$). Tukey HSD post hoc test showed that the there was a statistically significant difference between MS and SB ($p = 0.02$) and a trend toward significance between MS and VB ($p = 0.06$). An ANOVA between position

on the field and average SA showed no significance ($p = 0.18$). The regression analysis showed non-meaningful results. **Conclusion:** According to this study, position on the field does not have a noticeable effect on SA in athletes, however the type of sport (upper body or lower body) and gender may have an effect of the SA of athlete with a possible relationship between the two variables gender and upper body or lower body sports. Future studies may want to investigate that relationship further. Additionally, future research may want to collect a larger sample size to increase statistical power when running data analysis. **Practical Applications:** Being able to rank or order sports from highest, or most positive (favoring the right) to lowest, or most negative (favoring the left) due to developed asymmetry could justify strength and conditioning coaching to implement more unilateral movements to possibly decrease the imbalances in athletes.

Acknowledgements

I want to first and foremost thank my committee members for all of their time and support through this vigorous process. Specifically, I would like thank Dr. Tracey Robinson for her time and effort correcting and revising multiple drafts, and her patience with me for my random and unscheduled visits to her office. I would like to thank Mr. Lukus Klawitter for all of his help and willingness to respond to messages and emails at all hours, day or night, and responding promptly. I would like to thank Dr. Robert Astalos for working tirelessly with me day after day during the statistical analysis portion of this process.

Thank you to all the athletes who participated in this research, and took the time out of their busy schedules to participate. Without your participation this study would not exist, and could not potentially help other athletes in the future stay happy, healthy and balanced.

I would like to also thank my research assistants, my fellow cohort members, and anyone who took time out of their schedule to help and assist in the process of this study. Without their help, guidance and constant support, this process would have been overwhelming. I would also like to thank them for being extremely understanding in my times of being distracted, easily agitated, and my lack of empathy during the time it took to complete this research.

Most importantly I would like to thank God, my family, and my friends who kept me motivated to continue when I couldn't do that for myself.

Chapter 1: Introduction

Marcus Vitruvius Pollio, more commonly known as Vitruvius, a Roman architect once said, "Without symmetry and proportion there can be no principles in the design of any temple; that is, if there is no precise relation between its members, as in the case of those of a well-shaped man" (Vitruvius & Granger, 1931). Vitruvius states in his work on architecture that the measurements of man are arranged by nature: for example, four fingers make one palm, four palms make one foot, six palms make one cubit, and four cubits make a man's height (Leonardo & McCurdy, 1939). Vitruvius authored a treatise on architecture titled "De Architectura". This treatise is made up of ten books, with each book dealing with a different area of architecture. The third book titled, "The planning of temples" is where Leonardo Da Vinci got the idea for the famous painting called the *The Vitruvian Man* (Leonardo & McCurdy, 1939). It can be argued that when Vitruvian titled the third book, he had a more divine idea than an actual temple: that is, the Gods or the perfect man would have these dimensions. Today's human race is far from perfect in that sense. A Greek Philosopher born 427 B.C., by the name of Plato, wrote that over half of the population had a leg length asymmetry from a quarter-inch to three-quarter inches (Laughlin 1998; Newton et al., 2006; Plato & Lee, 1974). People are not only asymmetrical in a physical manner, such as limb length or proportionality, but are also asymmetrical in a physiological manner, more specifically in force output (Newton et al, 2006).

Newton et al. (2006) concluded that asymmetrical force output in people comes down to limb length, handedness, or repetitive movement such as sports movement (Newton et al., 2006). According to McCaw and Bates (1991), there are three definitions to leg length inequality: a functional short leg, an anatomical short leg, and an environmental limb length inequality. A functional short leg is where one limb is shorter than another because of a physiological problem, such as a rotated hip (McCaw & Bates, 1991). An anatomical short leg consists of a measurable difference in bone length between the limbs (McCaw & Bates, 1991). An environmental limb length is when the environment is what causes the body to be asymmetric, such as the drainage slope on a road (McCaw & Bates, 1991). Two out of the three causes of limb length inequality are muscular imbalances and skeletal imbalances. Muscular imbalances are more common than skeletal imbalances because of the imbalances in repetitive sports movements, specifically in highly skilled sports (Kugler, Krüger-Franke, Reininger, Trouillier, & Rosemeyer, 1996). In a sport like volleyball a highly skilled player (hitter) attacks the ball approximately 40,000 times a year (Kugler et al., 1996). This difference in amount of arm swing can cause an asymmetry between muscles when comparing playing shoulder and non-playing shoulder (Kugler et al., 1996). Asymmetry developed in that manner is not unique to a sport like volleyball and is not unique to upper body sports. Sports like soccer where the action is in the lower body, the same asymmetry is developed when an athlete continuously kicks the ball with their dominant leg versus their non-dominant leg (Lees, Asai, Anderson, Nunome, Sterzing, 2010). Kicking is not the only action that can cause an asymmetry in the body; repetitive movement or continuous movement on the field may play a role in how asymmetry is developed. This study investigated whether position played on the field affected symmetry in lower body force output.

Asymmetrical force output potentially, depending on the severity, can be a major problem for athletes and strength and conditioning (SC) coaches because it can cause athletes to be categorized as "high risk" for injury (Bell, Sanfilippo, Binkley, & Heiderscheit, 2014; Hewit, Cronin, & Hume, 2012; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007). Athletes are classified as "high risk" when there is a recorded asymmetry of approximately 15% (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007). With athletes having a resistance training background. Newton et al. (2006) suggest that it is surprising that imbalances exist, because resistance training is a way to correct imbalances. This high risk for injury is why there needs to be more research on lower body force output. To the best of the primary investigator's knowledge, research that is on lower body force output covers asymmetric force output during some variation of jump, such a countermovement jump, squat jump, vertical jump, or single leg jumps. The primary investigator would like to broaden the base of research and investigate lower body force output while under an external load (i.e. the back squat). Newton et al. (2006) hypothesized that the dominance of movement of one side of the body during skills training and competition perpetuates these imbalances, and specific resistance training targeting the weaker side may be required. In the example of kicking a soccer ball, the left leg is the leg that absorbs forces, or the stance leg, allowing the right leg or swing leg to execute the desired movement (when right-side is dominant) (Dessery, Barbier, Gillet, & Corbeil, 2011). In different sports, it can be assumed that executing a sport-specific movement requires a different force profile than another. This assumption can be made because of Newton's second law which states that force equals mass times acceleration (DeWesse & Nimphia, 2016). Each sport has different sports implements, with different shapes and different weights, and is manipulated differently; each requires a different amount of force to be displaced or moved appropriately. For example, a hockey puck is disk-like in nature (one inch thick and three-inch diameter) which weighs six ounces, and is manipulated by a hockey stick (Hockeygiant). In contrast, a college football is approximately 10.5- 11.5 inches in length, with a circumference of roughly 28 and 21 inches on the long side and short side respectively, and is thrown through the air (Big game football factory, n.d.). Not only do different sports use different implements, but different sports have different ways of manipulating their implements. For example, this study included participants from different sports, such as volleyball, soccer, baseball and softball. Volleyball, baseball, and softball use the upper body to manipulate the sport's implement (i.e. hitting and throwing a ball), while soccer uses the lower body to manipulate its sport implement (i.e. kicking a ball).

Symmetry traditionally is measured with an index; two of the more common indices are the Bilateral Index (BI), and the Limb Symmetry Index (LSI) (Bell et al., 2014; Koh, Grabiner, & Clough, 1993; Luk, Winter, O'Neil, & Thompson, 2013; Menzel et al., 2013; Simon & Ferris, 2008). Symmetry index is one of the most common methods of quantifying asymmetry between discrete measures such as force output between limbs (Zifchock, Davis, Higginson, & Royer, 2008). This study measured symmetry by using a symmetry angle (SA). SA is a measure of the relationship between discrete values measured from the left and right-sides (Zifchock et al., 2008). Then it is related to the angle formed when a right-side is plotted against the left side value: (X_{right}, X_{Left}) (Zifchock et al., 2008). When using SA to measure asymmetry, a reference value does not need to be established, and SA does not yield an over-inflated measurement (Bishop, Read, Chavda, & Turner, 2016; Zifchock et al., 2008).

Purpose of study

The purpose of this study was to determine if there was a correlation between lower body force output asymmetry and positioning on the field in NCAA Division II collegiate athletes by measuring force output using SA while performing a barbell back squat (BS).

Research questions

1. Is there a difference in SA between sports?
2. Is there a relationship between position played on the field and SA in athletes?
3. Is there a difference in SA between men and women?
4. Do athletes that play on a specific third of the field (right, center, or left) have a different

asymmetry angle than an athlete that plays on another third of the field?

5. Does position played on the field, gender, or sports predict asymmetry in athletes?

Hypotheses

The primary investigator hypothesized that athletes that play on the right-side or left side of the field would have a larger (meaning further away from zero or the line of symmetry) symmetry angle (SA) than an athlete that plays in the center of the field when performing the BS because of repetitive sports-specific movement that accompanies playing on a specific side of the field. For example, since the left leg is the leg that absorbs forces, or the stance leg, allowing the right leg or swing leg to execute the desired movement (when right-side is dominant), executing a sports-specific movement from the right-side requires a different force profile than a sports-specific movement from the left side (Dessery et al., 2011). The primary investigator also hypothesized that there would be a different symmetry angle measured by the BS between soccer players and other athletes, because soccer is a lower body sport and the SA is being measured by a lower body exercise. Soccer players have a more specific skill set for this test compared to the other sports of baseball, softball, and volleyball.

Significance of study

The significance of this study is to add to the research by investigating a possible reason why a bilateral strength difference in athletes is present (Newton et al., 2006). Research has stated that many athletes are asymmetrical in nature, but the question is why? This study specifically focused on position on the field and its relationship to asymmetric lower body force output in athletes.

Delimitations

This study was delimited as follows:

1. This study only included NCAA Division II athletes.
2. This study only included sports (i.e. soccer, volleyball, baseball, softball) that have positions that stay within a specific portion of the field (e.g. left defender in soccer, centerfield in baseball or softball, and right-side hitter in volleyball).
3. This study was conducted during the athletes' off-season.
4. In this study the BS was tested at a submaximal effort of 70% of 1RM.
5. This study was conducted at an altitude of approximately 7,500 ft. above sea level.
6. This study only examined male and female soccer, female volleyball, softball, and baseball players, ages 18-25 years.
7. This study only looked at bilateral force output values (measured using force plates) as a way to measure lower body asymmetry.
8. This study described asymmetry as the difference in force output between the left and right lower limbs.

Limitations

This study was limited as follows:

1. This study was conducted at the altitude of approximately 7,500 ft. above sea level.
2. The results of this study are only applicable to Division II athletes that participate in men's and women's soccer, women's volleyball, baseball, or softball.
3. This study may have different levels of asymmetry in each individual. This means that each athlete having a different sports background and playing different sports that require

different sports specific movements would likely have a different level of asymmetry.

4. This study's participants have only reported their current positions, and the amount of experience (yrs.) at the current position, not taking inconsideration, the amount of time played at other positing's and how that time (in years) could possibly affect the results.
5. This study's participants had different levels of physical health prior to participating in the research. This means that because the participants ranged in age, training age and playing experience, each participant may have a different level of fitness when starting the data collection. A freshman volleyball player likely had a different level of fitness than a senior baseball player. It is uncertain if age or playing experience has an effect on SA in athletes.
6. This study measured SA in only one of the three axial directions (vertical). To have a complete SA force profile, all three planes of motions must be measured (Hewit et al., 2012).
7. This study described asymmetry as the difference in force output from the left limb to the difference in the force output in the right limb.

Assumptions

The assumptions for this study were:

1. That every participant participated voluntarily.
2. That every participant confidently and competently understood and executed the BS technique and protocol, as requested by primary investigator.
3. That the SA index was valid measurement of asymmetry in lower body force output.
4. That every participant was in good mental and physical health while participating in the

research.

5. That each participant gave full effort during the data collection.
6. That different sports specific movements from each sport had a different lower body force profile.
7. That sports that have a specification to the position on the field (i.e. right, left or center), the athletes playing that position spent a majority of the time there (i.e. right, left, or center).

Definitions of terms

ANOVA: A statistical model used to analyze situations that have more than two conditions (Field, 2016).

Anatomical position: The erect position of the body with the face direction forward, arms at the side and the palms of the hands facing forward. This position is used as a reference in describing the relation of the body parts to one another (DeWesse, & Nimphia, 2016).

Asymmetry: Lack of equality between parts or aspects of something; lack of symmetry. In this study, asymmetry was defined as the difference between the right and left lower limbs and was be measured using the SA = $(45° - arcTan(X\_Left/X\_Right))/(90°) * 100\%$ (Bishop et al., 2016; Zifchock et al., 2008).

Bivariate: A correlation between two variables which is measured with the Pearson's correlation coefficient (Field, 2016).

Closed Chain: Physical exercises performed where the foot is fixed in space and cannot move. The extremity remains in constant contact with the immobile surface, usually with the ground or the base of a machine; effective for strengthening and rehabilitation (i.e. back squat) (DeWesse, & Nimphia, 2016).

Concentric Muscle Action: The muscle shortens because the contractile force generated inside the muscle is greater than the force of resistance acting to lengthen the muscle (DeWesse, & Nimphia, 2016).

Countermovement Jump (CMJ): The participant starts from an upright standing position, makes a preliminary downward movement by flexing at the knees and hips, then immediately extends the knees and hips again to jump vertically up off the ground (DeWesse, & Nimphia, 2016).

Eccentric Muscle Action: The muscle lengthens because the contractile force generated inside the muscle acting to shorten the muscle is less than the resistive force (DeWesse, & Nimphia, 2016).

Electromyography (EMG): A diagnostic system that uses remote surface EMG sensors to read the electrical signal emitted by the motor neurons of a muscle (Brandon, Howatson, Strachan, & Hunter, 2015).

Exterior Group: Players whose positions on the field are not in the center third of the field.

Force: Strength or energy as an attribute of physical action or movement (DeWesse, & Nimphia, 2016). The equation of force in $F = M * A$. In this study force were measured by using force plates in Newtons.

Force Plate: A device that measures radial force by means of a platform that participant's stand, jump, and squat upon (Bell et al., 2014). In this study, the force plates measured peak force exerted by the right and left lower body limbs while performing a BS.

Goniometer: An instrument for the precise measurement of joint angle.

Healthy: An athlete that is cleared to compete in collegiate athletics.

Independent T-Test: A test using a t-statistic that determines if the difference between two means is statistically different (Field, 2016).

Interior Group: Players whose positions are located in the center third of the field.

NCAA: The National Collegiate Athletic Association is a nonprofit association committed to providing opportunity for more than 460,000 college students who compete annually in college sorts.

One Repetition Max (1RM): A value used to represent an amount of weight moved at one time giving maximal effort (Brandon et al., 2015).

Open Chain: Physical exercises that are performed where the foot is free to move; effective for strengthening and rehabilitation (i.e. prone hamstring curl) (DeWesse, & Nimphia, 2016).

Pasco computer software: A computer software used for collecting various forms of analytical data.

Post-Activation Potentiation: Is the theory of lifting weights and then performing an explosive movement with a higher energy potential (DeWesse, & Nimphia, 2016).

Post-hoc Test: A test in which every comparison between groups is measured (Field, 2016).

Range of Motion (ROM): The full movement potential of a joint in the body (DeWesse, & Nimphia, 2016).

Regression: Also known as a simple regression, it is a linear model where an outcome can be predicted from a single predictor variable (Field, 2016).

SPSS: A computer software used to run analytical tests.

Stretch Shortening Cycle (SSC): An active stretch of a muscle followed by an immediate shortening of the same muscle (DeWesse, & Nimphia, 2016).

Symmetry Angle (SA): The measurement of the relationship between discrete values obtained from the left and the right-sides (Zifchock et al., 2008) See asymmetry definition above for equation.

Torque: Force that causes rotational movement and is also often called a moment of force (McGinnis, 2013).

Unilateral movement: A movement that only affects one side of the body versus both sides (DeWesse, & Nimphia, 2016).

Chapter 2: Review of Literature

Introduction

Specific jumping tasks including the drop jump, maximal vertical jump, and single leg hop, have been researched via force production. However, limited focus has been on force production and individual asymmetry in sport (Hodges, Patrick, & Reiser, 2011). There is a lack of research on bilateral strength difference in athletes; therefore, it is unclear if the imbalances are from sport-specific skills or other factors including injury (Newton et al., 2006). It was evident that training not only influences peak performance variables but also elicits changes in the power, force, velocity, and displacement time curves throughout the countermovement jump (CMJ) (Cormie, Mcbride, & McCaulley, 2009). Also, researchers have concluded that a bilateral asymmetry in lower body force output was present when performing the barbell back squat (BS) (Impellizzeri et al., 2007; Menzel et al., 2013; Newton et al., 2006). Movements that are found to be asymmetric, not including the BS, are single leg CMJ and double leg CMJ. Other factors that may be related to asymmetry that have been researched are gender and fatigue (Brandon et al., 2015).

The research of Jakovljević, Karalejić, Pajić, Janković, & Erčulj (2015) focused on the relations between abilities of professional basketball player in the performance of a 1RM BS and high rate of force movements such as the 5-, 10- and 20-meter runs, and vertical jumps. Jakovljević and colleagues (2015) studied 35 professional Bulgarian basketball players, average age 21.37 ± 2.91 years, in two tests, the 1RM BS and a 20-meter run that had photo cells positioned at 5-, 10- and 20-meters from the starting line, at a height of 1 meter (Jakovljević et al., 2015). The researchers showed that none of the variables of strength were significantly related to the speed of the performance, while moderate correlations occurred between the normalized strength variables and vertical jump, strength normalized to each athlete's individual weight. The variables of strength included 1RM BS, 1RM BS/kg, and 1RM BS allometric, where the BS/kg and the BS allometric are normalized versions of the 1RM BS (Jakovljević et al., 2015). These researchers concluded the same asymmetry was present when performing a BS at a slow cadence and at a faster cadence (Jakovljević et al., 2015). Other researchers ascertained larger asymmetric values when subjects were instructed to generate force rapidly rather than gradually (Koh, Grabiner, & Clough, 1993). In the current study, each participant performed the BS at their own controlled pace since this study was not focused on the speed of the BS. This study investigated whether the asymmetry that is present while performing a BS was due to repetitive sports movements based on position on the field.

According to Sato and Heise (2012), when quietly standing on a force place, the lower body force output values were asymmetric; this means asymmetry was present in stationary tasks (anatomical position), as well as dynamic tasks such as the BS. Other researchers showed that the lower body force output values were also asymmetric when performing a CMJ (Impellizzeri et al., 2007; Menzel et al., 2013; Newton et al., 2006). Adams, O'Shea, O'Shea, and Climstein (1992) stated that the BS and vertical jumps (e.g. CMJ), are biomechanically similar because of the enhanced neuromuscular efficiency which allows for transfer of power from the BS to the CMJ. In addition to the CMJ and the BS using similar movements, and being similar in muscular activation, it can be hypothesized that there should be an asymmetry in lower body force output when performing a BS (Adams et al., 1992; Jakovljević, et al., 2015; Robbins, 2011).

Traditionally, lower body asymmetry has been calculated as a difference in unilateral jump height (JH) or jump distance. Bilateral movements such as the CMJ are increasing in use when evaluating injuries in athletes (Hewit et al., 2012; Hooper et al., 2014). The following literature review discusses asymmetry in the lower body limbs, more specifically the asymmetry in force output between the left and right lower body limbs while performing a BS. This study measured asymmetry by ground reactive force to expand the research on how asymmetry can be measured.

Force

Force is a vector with direction, and quantity or magnitude and is measured in units of Newtons (N) (DeWesse & Nimphia, 2016; Young, 1992). Force gives a quantitative description on an interaction between two objects or between an object and the universe around it (Young, 1992). An object can exert a force on another object, therefore force can be described as the interaction between two or more objects acting on each other (DeWesse & Nimphia, 2016). Force is traditionally explained as a push or a pull force which is the reason why two objects cannot occupy the same space (DeWesse & Nimphia, 2016). The equation of force is $F = M * A$, where M stands for mass and A stands for acceleration. When talking about the BS, internal forces exerted by the muscles (lean mass) that are located in the lower body act upon the object, the body, and that force(s) causes a change in direction which results in the object to leave the space it was occupying or to accelerate (DeWesse, & Nimphia, 2016).

Barbell back squat

The BS is a highly popular exercise to strengthen the primary mover muscles of the lower limbs and is an integral component in the sports of competitive weightlifting and power lifting; it is also regarded as the best test of lower body strength (Braidot, Brusa, Lestussi, & Parera, 2007;

Schoenfeld, 2010). The BS can be performed using just body weight or with an external load (i.e. barbells and dumbbells) (Schoenfeld, 2010). The BS begins with the participant in an upright position with their knees and hips fully extended (Schoenfeld, 2010). The participant then squats down by flexing at the hip, knee, and ankles joints (Schoenfeld, 2010). When the desired position is reached (see Figure 1), the participant reverses the action and direction, and ascends back to the upright position (Schoenfeld, 2010). Completing this action recruits most of the muscles in the lower limbs: quadriceps femoris, hip extensor, hip adductors, hip abductors and triceps surae (Schoenfeld, 2010). In all, it's estimated that about 200 muscles are activated during the BS (Schoenfeld, 2010).

Figure 1. Desired squat position (Baechle & Earle, 2008).

The BS was one of the most frequently used exercises in the field of SC (Braidot et al., 2007; Schoenfeld, 2010). Different variations of the BS have been found to be more beneficial than other variations when training specific muscles of the lower body. Research showed that when comparing BS to squats on a Smith machine, there was a 43% higher muscle activation in the lower limbs when performing the BS when compared to the Smith machine (Schwanbeck, Chilibeck, & Binsted, 2009). According to Schwanbeck et al. (2009), knee extensors, flexors, and ankle plantar flexion showed higher activation when the BS was performed (Schwanbeck et al., 2009). A few common areas of the BS that researchers all cover are the kinematic and kinetics of the ankle, knee, hip joint, and lifting technique.

Ankle joint

The ankle joint is complex and comprised of the talocrural and subtalar joints (Schoenfeld, 2010) (see Figure 2). The primary action at the subtalar joint is to maintain postural stability and limit eversion or inversion at the foot (Schoenfeld, 2010). During the BS, the talocrural joint facilitates movement through the actions of dorsiflexion and plantar flexion (Schoenfeld 2010). However, according to Schoenfeld (2010), kinematic data of the ankle during squatting is limited because a majority of the studies have focused on the biomechanics of the hip, knee, and spine (see Figure 2).

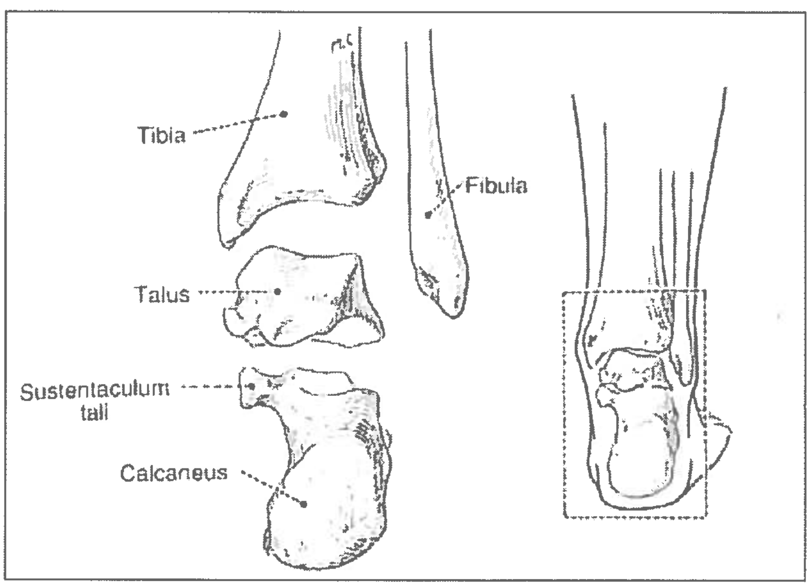

Figure 2. Ankle joint (Hamilton, Weimar, & Luttgens, 2008)

Knee joint

The strength and stability of the knee or the tibiofemoral joint plays an integral role in athletics and everyday physical activities (Gullett, Tillman, Gutierrez, & Chow, 2009). The tibiofemoral joint can be classified as a modified hinge joint that comprises the articulation of the tibia and femur (Schoenfeld, 2010). The patellofemoral joint assists the knee joint (Schoenfeld, 2010) (see Figure 3). The patella is the largest sesamoid bone; sesamoid bones are the bones that belong to the flat bone category located on the anterior side of the femur at the knee joint (Hamilton et al., 2008). The patella serves as a pulley of the quadriceps muscles since all four of the quadriceps muscles converge at the patella; the patella functions to increase the mechanical axis of the quadriceps through the patellar ligament (Hamilton et al., 2008).

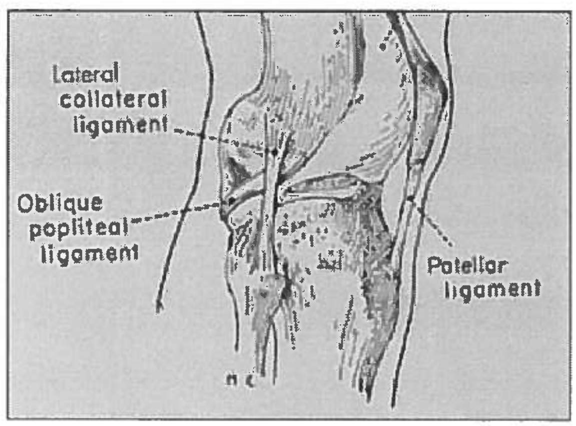

Figure 3. Patella joint (Hamilton et al., 2008)

The knee is made up of an array of ligaments and cartilage (Schoenfeld, 2010). The primary pair of ligaments in the knee include the anterior cruciate ligament (ACL), and the posterior cruciate ligament (PCL) (Schoenfeld, 2010) (see Figure 4). The ACL and the PCL can be considered counterparts, with their main function being the prevention of posterior and anterior translation (Schoenfeld, 2010).

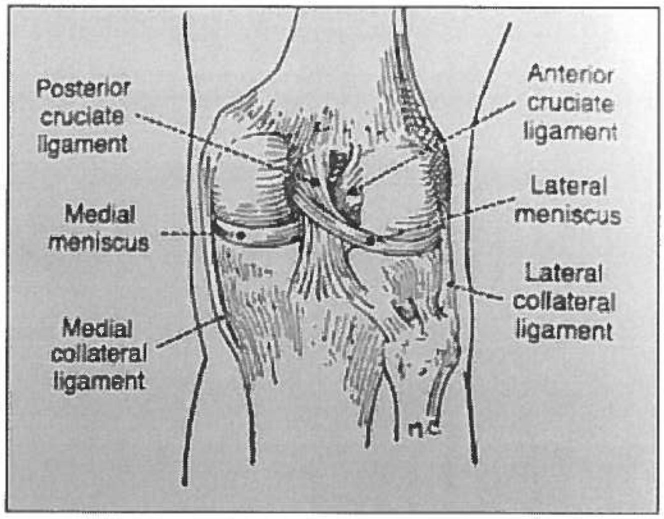

Figure 4. ACL and PCL (Hamilton et al., 2008)

The next set of ligament pairs are the medial and lateral collateral ligaments (MCL, LCL) that stabilize the knee in the frontal plane (Schoenfeld, 2010) (see Figure 5). Schoenfeld (2010) states that the main function of the MCL and LCL is to help provide resistance against varus and or valgus movements. These four ligaments are the main stabilizers of the knee joint; however, there are muscular insertions and origins that also help with stabilization.

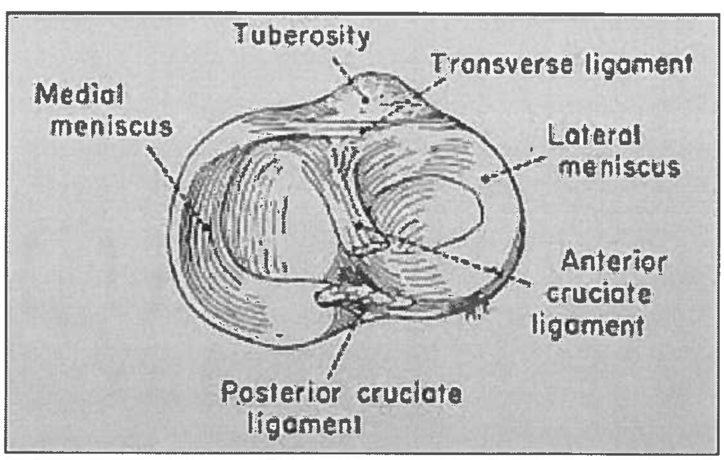

Figure 5. LCL and MCL (Hamilton et al., 2008)

According to Schoenfeld (2010), the primary muscles acting about the knee are the quadriceps femoris (vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris) and the hamstrings (biceps femoris, semitendinosus, and semimembranosus), which are the antagonists to the quadriceps. Braidot et al. (2007) explain that when performing a BS, the energy that goes through the knee was greater when performing a front squat, a variation of the BS, which allows for a greater muscular exercise when performed at the same load. This means that if a front squat was done at the same weight as a BS, the front squat would show a greater muscular gain in strength than the BS. This was in agreement with Gullett et al. (2009) who state that the BS resulted in higher compressive (proximal/distal) forces on the knee than the front squat. This means that there are less compressive forces acting on the knee joint when performing the front squat than the BS. However, because of the level of difficulty and amount of strength required, the front squat was performed with less weight compared to the BS. Compressive force is an axial stress that tends to push molecules together or squash the object (McGinnis, 2013).

Hip joint

The hip joint consists of a ball-and socket joint made up of the head of the femur and the acetabulum of the pelvic girdle, which allows for three plans of movement (Schoenfeld, 2010) (see Figure 6). Schoenfeld (2010) states that during the BS, hip torque increases in hip flexion with maximal torque taking place near the bottom phase of the movement.

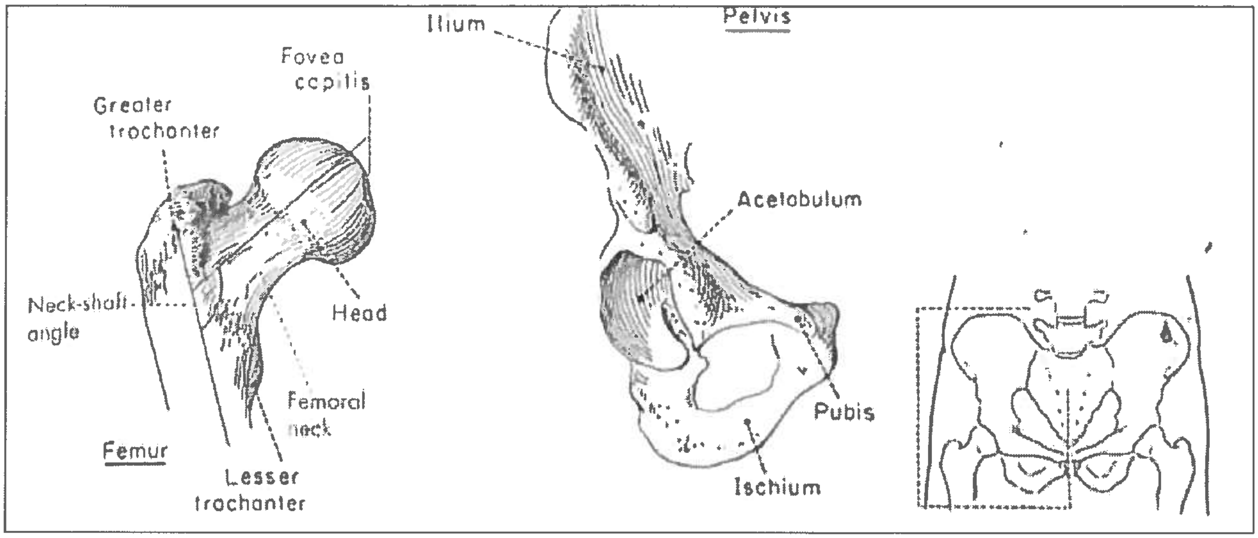

Figure 6. Hip joint (Hamilton et al., 2008)

Torque at joints

In a study done by Fry, Smith, and Schilling (2003), where researchers studied the effect of knee position on hip and knee torques during the BS, researchers found a significant difference between the two squat conditions (restricted and un-restricted) for torque at both the knee and the hip (see Figure 7) (Fry et al., 2003). Fry et al. (2003) studied recreationally weight trained men that use a high bar parallel squat technique in their current training regimen, who had been performing the BS for a minimum of one year, and could BS one-and-a-half times their body weight (N = 7; age 27.9 ± 5.2 years). The high bar parallel squat was defined as a barbell sitting on the superior aspect of the trapezius, while feet are place shoulder width apart (Fry et al., 2003). Parallel was defined as the inguinal fold (the groin area) being level with the superior aspect of the knee (Fry et al., 2003). Each participant performed three un-restricted and three restricted high bar parallel BS (Fry et al., 2003). The un-restricted high bar BS consisted of the high barbell placement with feet shoulder width apart and no impedance to the knees (see Figure 7A). The restricted high bar BS was the same, however there was a wooden board place immediately in front of the first digit of both feet (see Figure 7B).

For the un-restricted BS the results showed that the knee joint torque was greater than the torque measured at the hip joint. For the restricted BS the results showed less torque at the knee joint versus the hip joint (Fry et al., 2003). The un-restricted squat resulted in a more vertical shank and more inclined torso when compared to the restricted BS, while the restricted BS showed less knee and ankle flexion when compared to the un-restricted squat (Fry et al., 2003).

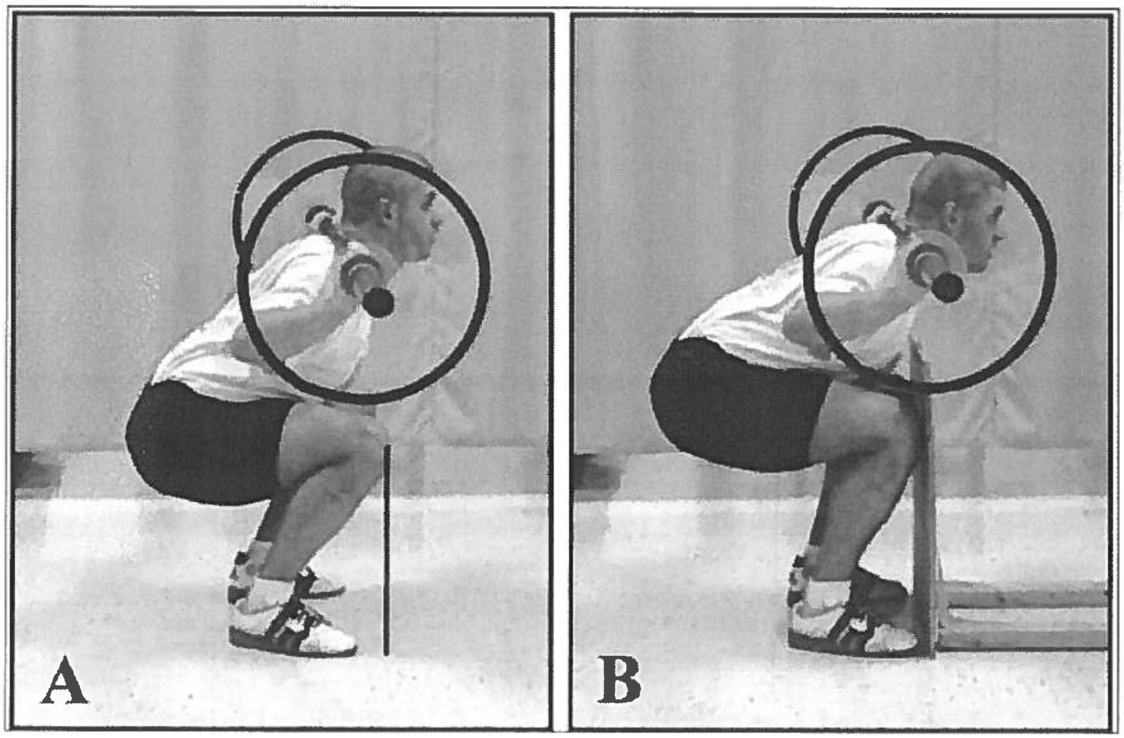

Figure 7. Un-restricted BS (A) versus restricted BS (B) (Fry et al., 2003).

This study did not regulate the placement of the shank or measure the amount of torque at the hip, knee, or ankle. This study measured the force output by both left and right legs while performing a BS. Fry et al. (2003) stated that BS exercise guidelines cite the need to keep the knees from moving past the toe threshold in the anterior direction or to keep the shank as vertical as possible when performing a BS. However, Fry et al. (2003) stated that in order to optimize the forces involved at all joints, it may be advantageous to change technique and allow the knees to move slightly beyond the threshold of the toes.

Back squat lifting technique

Technique is a very important factor when performing the BS. Research reveals that initial improvement in the BS was mainly due to improvement in BS technique (Čović, 2015). Correct foot placement, proper depth on each repetition, and the speed at which the BS was performed are all ways that can improve BS technique. A BS is defined by the hips descending below the level of the knee at the bottom of the movement (Brandon et al., 2015; Newton et al., 2006).

According to Gullett et al. (2009) front squats may be advantageous for people with knee problems such as ligament and meniscus tears, as well as for general long-term joint health. It has been observed that in the knee, there was a better development of energy with the front squat versus the BS (Braidot et al., 2007). However, the mean power absorbed by the hips when performing the BS was considerably higher, and associated with the speed of the movement (Braidot et al., 2007). Front squats could also be beneficial to people who have shoulder injuries or are lacking in range of motion (ROM) to grip the bar during a BS (Gullett et al., 2009). In this study the knee, hip, and ankle joints bear all of the weight of the movement, therefore only participants with healthy joints that are functioning through a complete and normal range of motion participated in this study. This means that this study only used healthy athletes that are currently playing and are cleared to play.

Squat protocol

Previous research on BS protocol revealed many commonalities. Schoenfeld (2010) states that a factor of greater clinical importance during the BS it how a load affects the spinal kinetics and kinematics. Researchers were consistent with using a constant load of 60 to75% of 1RM during the researchers' procedures (Brandon et al., 2015; Čović, 2015; Hooper et al., 2014; Lawrence & Carlson, 2015; Newton et al., 2006; Ojeda, Rios, Barrilao, & Serrano, 2016; Sato & Heise, 2012; Witmer, Davis, & Moir, 2010).

Brandon et al. (2015) had each participant perform incremental loaded sets and assessed the intensity of the lifts against a rate of perceived exertion (RPE) scale. The research of Brandon et al. (2015) had participants lift in three different sessions at three different weights: a light, moderate, and heavy session. The heavy session corresponded to lifts that were perceived at 16-17 on the RPE scale. Based upon the participant's current repetition maximum the 16-17 RPE equated to about 85% of the participant's 6 ± 1 repetition max (Brandon et al., 2015). For the BS, the light and moderate session participants lifted 50% and 75%, respectively of six repetition maximum (Brandon et al., 2015).

Čović (2015) put the participants into three groups: a control group, a slow speed group and a fast speed group, and used a 70% 1RM BS intervention at the different speeds. The slow speed group was instructed to perform each BS, eccentric and concentric, for four seconds each, and were verbally guided on the squatting speed throughout the squat (Čović, 2015). The fast speed group was instructed to complete the BS in the shortest time possible (Čović, 2015). The control group was instructed to maintain their lifestyles (Čović, 2015). This means that there was no intervention given to the control group. The results showed the total time of the BS execution was lower for the fast speed group compared to the slow speed group ($p < 0.001$)

(Čović, 2015). This means that the fast speed group performed the BS faster than the slow speed group. Compared to the control group, both the slow speed group and fast speed group improved their squat performances significantly, by 16% ($p = 0.001$; 95% CI 8.44-28.8%) and 19% ($p = 0.042$; 95 CI 0.27-20.6%) respectively (Čović, 2015). From the start of the study to the end, the slow speed group improved squat results significantly by 22.8% ($p < 0.001$: 95% CI 15.3-26.5%), the fast speed group improved significantly by 25% ($p < 0.005$; 95% CI 14.6-27.3%), while the control group did not improve significantly (Čović, 2015). Since there was no difference between the fast and the slow groups in the study done by Čović. (2015), the primary researcher did not monitor the speed at which the BS was executed. This study had the participants perform the BS at the same 70% 1RM when measuring SA. However, in this study, the speed of the BS was not monitored; each participant completed each BS at their own speed. Sato and Heise (2010) state that asymmetry is present while quietly standing and while performing a CMJ. Since this study measured SA, and not speed of the squat, the speed at which participants perform a BS should not affect that SA.

Lawrence and Carlson (2015) had 15 male resistance-trained volunteers BS 60% 1RM under two conditions, stable and unstable, while vertical ground reaction forces were recorded. The 15 participants (aged: 24.2 ± 3.4 yrs., body mass: 83.4 ± 18.7 kg, height: 1.7 ± 0.1 m, years lifting: 8.1 ± 4.3, 1RM: 131.4 ± 21.4 kg), all volunteered for this study and passed all exclusion criteria such as lower limb surgeries (Lawrence & Carlson, 2015). A result of Lawrence and Carlson's (2015) study showed the unstable condition produced significantly greater integrated (EMG) in the external obliques ($p < 0.01$). This means that the external obliques, a stabilizer muscle for compressive forces, was more active when squatting with an unstable load versus a stable load (DeWesse, & Nimphia, 2016). This study used a percentage similar to the one used in the study of Lawrence and Carlson (2015). This study used 70% of 1RM and a stable load not an unstable load.

In the study done by Ojeda et al. (2016), these researchers used 4 sets of 5 rep of 30% 1RM, plus four reps of 60% and three 30m sprints with a two-minute rest. Similar to the study of Newton et al. (2006), one of the longer BS protocols, participants performed warm-up sets of 8,6,4,3 at 60, 65, 70, and 75% of 1RM respectively, then three sets of one at 80% of 1RM to parallel depth with two minutes rest between. The split times of the 10-meter and 20-meter sprints did not show any significant differences between the control set and the four experimental sets ($p = 0.46$ and $p = 8.80$ respectively) (Ojeda et al., 2016). However, there was a significant decrease in the 30-meter time between control set and the four experimental sets ($p = 0.0001$); this was attributed to post-activation potentiation in the lower limb muscles (Ojeda et al., 2016). In this study, each participant performed eight warm-up repetitions of the BS, then one repetition of 70% 1RM three separate times.

This study had the participants perform the BS at 70% of their 1RM. As loads increase, the linear velocity of the bar decreases and the vertical ground reactive force increases significantly (Kellis, Arambatzi, & Papadopoulos, 2005). Kellis et al. (2005) showed that the maximum ground reaction force was achieved with the knees flexed at approximately 104-115 degrees, the hip flexed 119-135 degrees and the ankle dorsiflexed at 72-84 degrees while performing a BS. It was also noted that, when the weight was between 40%-70% 1RM, a significant 16 degrees increase in forward lean was seen when subjects lifted (Schoenfeld, 2010). This study focused only on the lower body force outputted by each participant; therefore, it was acceptable for each participant to perform a BS at 70% 1RM because the joint velocity coordination does not change as the load increases from 7% to 70% 1RM (Kellis et al., 2005).

This means that from 7% to 70% 1RM the speed at which each joint flex and extends does not change, according to Kellis et al. (2005). Also, the focus of this study was only the lower body force output, the primary investigator was not measuring the forward lean of each participant when performing a BS. Since forward lean acts at the hip, the effects of forward lean on force output can be considered negligible because it acts on both limbs evenly even if force output is not symmetric (Kellis et al., 2005).

Traditionally asymmetry has been measured by using various different types of jumps (Adams et al., 1992; Bell, Sanfilippo, Binkley, & Heiderscheit, 2014; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007; Jakovljević, Karalejić, Pajić, Janković, & Erčulj, 2015). Jumps, such as the CMJ, have been shown to be similar in muscular activation to the BS (Robbins, 2011).

Vertical jump

The vertical jump or CMJ is a test of power (Jakovljević et al., 2015). The CMJ can be influenced by two factors: increasing the lower body force output while maintaining the same speed of the jump, or by increasing the speed of the CMJ while maintaining the same level of lower body force output (Jakovljević et al., 2015). Jakovljević et al. (2015) studied 35 professional Bulgarian basketball players aged 21.37 ± 2.91 years. Two sub-groups were formed according to the position they played: perimeter players (N = 22), average age 20.90 ± 2.09 years, and post players (N = 13), average age 22.15 ± 3.91 years (Jakovljević et al., 2015). The results showed that the difference between the inside and outside players in terms of dependent variables were not very obvious, and statistically significant only in peak anaerobic power (PAPw) (Jakovljević et al., 2015). Jakovljević et al. (2015) showed that on average outside players reached better results in three acceleration variables: 5m, 10m, and 20m, but inside players reached better results in their 1RM and vertical jump (Jakovljević et al., 2015). The only variable found to be statistically significant was peak anaerobic power measured in Watts (W) ($p < 0.01$). Outside players' peak anaerobic power (PAP) was measured as PAP = 5567.70 ± 499.53 W, while the inside players' PAP was measured as PAP = 6072.00 ± 694.44 W.

Jakovljević et al. (2015) concluded that in both groups: post players and perimeter players, the force developed by training represents a latent ability whose positive transfer in maximum running speed is only possible through the conversion of force into explosive and speed power. This study measured force exerted by each lower limb. If the forces exerted are determined to be greater than 15% asymmetric, when an athlete converts that force into a high rate of power and speed, it may cause the athlete to deviate away from a desired path (Impellizzeri et al., 2007). This means that when an athlete converted the non-symmetric forces from the right and left lower limbs into a high rate of power and speed in a straight line that is not in the same line of action as the movement. The athlete deviated off of the desired straight line, because the non-symmetric forces are not pointed vertically.

Adams et al. (1992) studied 48 male participants that had a minimum of one year of recreational lifting experience and were enrolled in a strength training class at Utah State University. The participants were split into four groups: squats (S), plyometric (P), squat plyometric (SP), and control (C); each participant's 1RM was tested at the beginning of the training and hip and thigh power was tested before and after the six-week training session with the vertical jump test (Adams et al., 1992). Reliability of the vertical jump force test (VJFT) was reported at 0.93 (Bell et al., 2014; Adams et al., 1992). The participants were given three trials and the best score was recorded for statistical analysis (Adams et al., 1992). The results from

Adams et al. (1992) support the findings of Robbins (2011) that there was a link between maximal BS strength and vertical jump height. S and P training groups both had significant results in increasing hip and thigh power production when compared to the C group ($p = 0.019$, $p = 0.007$, respectively) (Adams et al., 1992). Examination of the pre- to post-training test mean scores showed that the S, P, and SP groups increased 3.30 cm, 3.81 cm and 10.67 cm, respectively in vertical jump height.

During a maximal CMJ, the work performed at the ankle, knee, and hip all influence performance due to the excessive muscular torque applied at each joint. However, during maximal CMJ, the hip has the greatest influence on performance by generating the most work because of torque compared to the ankle and knee (Bell et al., 2014). Knee extensor strength explains 23% of the variance in JH, whereas more functional assessments of strength, such as an isometric squat leg press, have a stronger association with JH and explain greater percentage of variance, 69% (Bell et al., 2014). Yet, CMJ was a valid way to measure lower body force asymmetry (Impellizzeri et al., 2007). When tested, the CMJ mirrors the movement of the BS (Impellizzeri et al., 2007).

The study of Impellizzeri et al. (2007) consisted of five different parts dealing with VJFT: correlation with isokinetic leg extension test, correlation with isometric leg press test, test-retest reliability, effect of sport rehabilitation, and normative data. The first part of the study examined the correlation between the vertical jump force test (VJFT) and the isokinetic knee extension test (Impellizzeri et al., 2007). The isokinetic knee extension test is the most commonly used test to assess bilateral strength asymmetry (Impellizzeri et al., 2007). Fifty-nine male athletes (age 26 ± 5 years, height 180 ±5 cm, and body mass 79 ± 6 kg) that participated in different sports (soccer, track and field, basketball, fencing, and alpine skiing) performed the

VJFT and isokinetic knee extension test with a minimum of 30 minutes of rest between the two tests (Impellizzeri et al., 2007). The only disadvantages of the isokinetic knee extension test are that it is open chain and isolates the knee extensor muscles (Impellizzeri et al., 2007). The correlations between bilateral strength asymmetry calculated with the isokinetic leg extension test and VJFT were moderate but significant for both 60 degrees per second ($r = 0.48$; 95% confidence interval: 0.26-.66; $p < 0.001$) and 240 degrees per second ($r = 0.48$; 0.26-0.66 $p < 0.001$) (Impellizzeri et al., 2007).

In lieu of the open chain isokinetic knee extension test, Impellizzeri et al. (2007) looked at the correlation between VJFT and bilateral strength asymmetry measured by the isometric leg press test. Forty-one male athletes (age 25 ± 4 years, height 178 ± 5 cm, body mass 78 ± 5 kg) that participated in the same sports as above performed the VJFT and isometric leg press test with a minimum of 30 minutes of rest between the two tests (Impellizzeri et al., 2007). The isometric leg press test is a closed chain and involves the knee extensors, hip extensors and the plantar flexors (Impellizzeri et al., 2007). A significant and very large correlation was found between bilateral strength asymmetry calculated with the isometric leg press test and bilateral strength asymmetry calculated with VJFT ($r = 0.83$; 0.70-0.91; $p < 0.001$) (Impellizzeri et al., 2007).

The third part of the study tested the test-retest reliability of the VJFT and was determined for protocols with different number of jumps (Impellizzeri et al., 2007). Sixty male athletes (25 ± 6 years, height 177 ± 4 cm, and body mass 76 ± 6 kg) that participate in the same sports listed previously, repeated tests in a gym on back-to-back days two to four hours after a light breakfast (Impellizzeri et al., 2007). Test-retest reliability of VJFT bilateral strength asymmetry can be seen in the Figure 8 below (Impellizzeri et al., 2007).

Number of Jumps	Change in the Mean	Limits of Agreement	Typical Error	ICC
First 1	−0.20 (−2.20 to 1.80)	± 15.2%	5.5% (4.6 to 6.7%)	0.58 (0.38 to 0.72)
First 2	0.14 (−1.20 to 1.47)	± 10.1%	3.7% (3.1 to 4.5%)	0.77 (0.64 to 0.85)
First 3	0.20 (−0.83 to 1.23)	± 7.8%	2.8% (2.4 to 3.4%)	0.86 (0.77 to 0.91)
First 4	−0.13 (−1.10 to 0.83)	± 7.3%	2.6% (2.2 to 3.2%)	0.88 (0.80 to 0.93)
First 5	−0.40 (−1.25 to 0.46)	± 6.5%	2.4% (2.0 to 2.9%)	0.91 (0.85 to 0.94)

In parentheses are the 95% confidence intervals. ICC, intraclass correlation coefficient.

Figure 8. Test-retest reliability of the vertical jump force test (Impellizzeri et al., 2007)

All residuals in the Bland-Altman plots showed no evidence of significant heteroscedasticity (R =0.02) (Impellizzeri et al., 2007). The changes in the means from test to retest were found not substantial (Impellizzeri et al., 2007). This means that the VJFT is a reliable test.

The fourth part of the study investigated the sensitivity of the VJFT to rehabilitation programs that are meant to reduce bilateral strength asymmetry in athletes recovering from knee surgery (Impellizzeri et al., 2007). Five male soccer players (age 23 ± 2 years, height 179 ± 4 cm, body mass 76 ± 5 kg), one female fencer (age 23 years, height 168 cm, body mass 53 kg), and one female volleyball player (age 19 years, height 175 cm, body mass 61 kg), who all were doing individualized rehabilitation after anterior cruciate ligament reconstruction (ACLR), participated in this study (Impellizzeri et al., 2007). Bilateral strength asymmetry was tested with the VJFT eight to twelve weeks after surgery (pre-test), while the post-tests were performed seven to nine weeks later during the return to play phase (Impellizzeri et al., 2007). The rehabilitation programs included open chain isotonic and plyometric exercises, and were performed in different rehabilitation centers, all of which occurred around the same time of day, three hours after consumption of a light meal (Impellizzeri et al., 2007). Impellizzeri et al. (2007) showed that there was a significant reduction in bilateral strength asymmetry of the lower limbs between pre-test (23 ± 3%) and post-test (10 ± 4%) ($p = 0.02$). The mean peak force of the uninjured leg did not change significantly between pre-test (938 ± 165 N) and post-test (998 ± 209 N) ($p = 0.50$); the mean peak force of the injured leg increased significantly from pre-test (725 ± 117) to post-test (980 ± 145 N) ($p = 0.02$) (Impellizzeri et al., 2007).

The last part of the study Impellizzeri et al. (2007) performed was to provide preliminary normative data of bilateral strength asymmetry assessed with the VJFT by screening soccer athletes. The VJFT was conducted with 313 male soccer players competing in Italy at professional, semi-professional, and amateur levels (age 25 ± 4.1 years, height 177 ± 5 cm, body mass 74 ± 7 kg) to provide preliminary reference values for bilateral strength asymmetry of the lower limbs (Impellizzeri et al., 2007). All participants were tested indoors at their own training facilities during the pre-season training period (from July to September), and were instructed to avoid strenuous exercise 24 hours prior testing (Impellizzeri et al., 2007). The mean peak force of the stronger and weaker legs measured during the vertical jump force test were 1036 ± 153 N and 972 ± 141 N respectively (Impellizzeri et al., 2007). The distribution was normal from the results of the Shapiro-wilk test (W = 0.995, $p = 0.47$); the normal range (95% confidence interval) was -15.1% (2.5^{th} percentile) and 15.0% (97.5th percentile) (Impellizzeri et al., 2007). This means that numbers falling outside of this confidence interval should be considered abnormal (Impellizzeri et al., 2007).

Impellizzeri et al.'s (2007) results showed a statistically significant correlation between the VJFT and the isokinetic leg extension test, which was the most common method used to compute bilateral strength asymmetry of the lower limbs in athletes. The shared variance between the VJFT and the leg press test is higher than between the VJFT and isokinetic leg extension test, 69% and 23% respectively (Impellizzeri et al., 2007). This was because the leg press and the isokinetic leg extension involve muscles at the ankle, knee, and hip joints. This suggests that these two tests measure the same construct, which is bilateral strength asymmetry of the lower limbs (Impellizzeri et al., 2007). The remaining variance can be explained by factors that influence CMJ performance, but not isometric strength (i.e., the ability to use the Stretch Shortening Cycle (SSC) and rate of force developed) (Impellizzeri et al., 2007). Impellizzeri et al. (2007) concluded that an open chain, isokinetic test should be used when there was a need to compute bilateral strength of specific lower limbs. However, both VJFT and closed-chain leg press test provide a universally accepted measure of bilateral strength asymmetry; which may be more functionally relevant to sports activities since sports activities require coordinated action of many lower limb muscles (Impellizzeri et al., 2007). The focus of this study was not the VFJT but, as mentioned earlier, there was a correlation between vertical jump and maximal BS strength (Impellizzeri et al., 2007).

Robbins (2011) stated that CMJ and the BS had similar muscular activation. With that it can be assumed that both the CMJ and the BS would fatigue in a similar manner.

Fatigue

When executing a BS, it is important to know how fatigue can alter the performance of the experience. Fatigue not only changes how a BS was executed, but fatigue affects people mechanically and physiologically differently. Researchers have shown that during a heavy BS load, participants were unable to maintain initial barbell velocity as repetitions and sets progressed (Brandon et al., 2015). For the elite populations, the absence of fatigue while performing a sub-maximum BS was an important benefit for typical athletic training (Brandon et al., 2015). If the BS form was changed to more of a stoop technique versus a squat, there is less flexion in the knee, allowing for the center of mass (CM) to move more anterior to the knee; this means there was less work required for the knee extensor muscle, thus decreasing performance (see Figure 9) (Hagen, Sorhagen, & Harms, 1995).

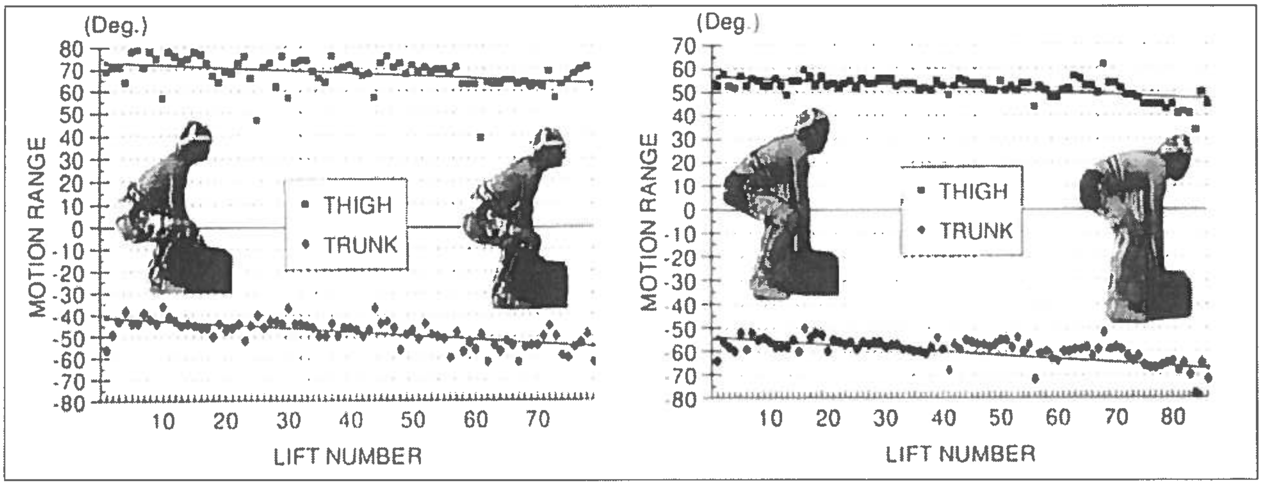

Figure 9. The difference between the stoop (right) and the squat (left) (Hagen et al., 1995).

According to Hagen et al. (1995), prior to the experiment each of the participants were educated on how to perform each maneuver. Each participant was instructed "to lift with extended elbows, bent at the knees, and erect back, (squat) or straight legs and bent back (stoop)" (Hagen et at., 1995, pg. 123). There was a significantly greater variation in thigh and lower-trunk motions, respectively, in the squat lifting motion compared to the stoop lifting motion (thigh $p < 0.01$ and trunk $p < 0.05$) (Hagen et al., 1995). This study had each participant perform three sets of one rep, to prevent fatigue from having an effect on the outcome of the data.

Hodges et al. (2011) showed that fatigue has no effect on ground reactive force in regards to asymmetry between left and right legs. However, other research showed that when measuring velocity in resistance exercise protocols (REP), the velocities of reps higher than eight had decrease (SáNchez-Medina & GonzáLez-Badillo, 2011). This suggests that fatigue was present in the exercise of the BS, but fatigue does not affect asymmetry in the lower body force output

(SáNchez-Medina & GonzáLez-Badillo, 2011). Decreased velocity was a predictor of fatigue in an exercise such as the BS, which sounds contradictory, but fatigue affects the BS bilaterally not unilaterally (SáNchez-Medina & GonzáLez-Badillo, 2011).

It was unclear the effects of fatigue on physical kinetics of the body. Knee and hip angle significantly changed in both men and women from the beginning of a 10-repetition set to the end of a 10-repetition set (Hooper et al., 2014). However, changes in hip and knee angles do not directly correlate to fatigue (Hooper et al., 2014). Hooper et al. (2014) showed that in an extreme conditioning protocol (ECP) that both men and women produce smaller hip and knee angles in the earlier repetitions of a set, repetitions one and two, compared to at the end of the sets, repetitions 8, 9 and 10. This could be from a self-preservation standpoint that mentally the body was saving the work that needs to be done by not going through the full range of motion to make sure that the full set can be completed (Hagen et al., 1995; Hooper et al., 2014). The research in this study had the participants perform three sets of one successful repetition of the BS with one-minute rest between each set; therefore, there should not be any change in form due to self-preservation. If the researcher had the participants perform the three reps of BS in one set, there still would not be any self-preservation in the BS technique since self-preservation was not evident until repetitions eight, nine and ten of a set (Hooper et al., 2014).

Asymmetry in fatigue responses can change in specific populations of people. According to Webster, Austin, Feller, Clark, and McClelland (2015), the baseline asymmetries were significantly reduced after fatigue in participants that had ACLR. According to Webster et al. (2015) a possible explanation for the shift toward symmetry after fatigue has taken place is that the lower body limb that did not undergo ACLR could only sustain carrying a heavier load for so long, and after some time it would have no choice but to distribute the some of the weight to the limb with the ACLR (Webster et al., 2015). Participants in this study must have healthy or normal functioning joints to perform in this study. Participants that have had ACLR and or are currently performing ACLR rehabilitation and have not been cleared by a medical professional were excluded from this study. Therefore, this study did not have to take this shift in asymmetry into consideration when analyzing the data.

There was research on various jumping tasks, such as landing a jump, performing a drop jump, performing a maximal vertical jump/CMJ, and a single leg hop, but there was limited research on the effects of fatigue and how fatigue influences asymmetry bilaterally (Hodges et al., 2011). To clarify, what Hodges et al. (2011) stated earlier, when performing a bilateral movement such as the drop jump or a maximal vertical jump/CMJ, the participant's lower body force output asymmetry did not change significantly. This means that when performing a bilateral jump, the asymmetry present in the lower limbs was not be affected by fatigue. This is in contrast to performing an individual jumping task such as single leg jump; fatigue did affect each lower limb, but at different rates because the strength level of each limb are different (Hodges et al., 2011). In simpler terms, a participant may be able to perform a maximal effort single leg hop five time on one leg, but perform a maximal effort jump ten times on the opposite leg, meaning one leg fatigues faster than the other. Fatigue had a minimum effect on the participants in this study since each participant performed one rep of the BS at a time while having a minute to rest between sets. According to Hodges et al. (2011), fatigue on the left and right lower limbs during bilateral movements was equal, even though general strength may be different in each limb during a similar unilateral movement compared to the bilateral movement.

Unilateral and bilateral movements

Bilateral movements/ exercise are movements that focus equally on both sides of the body: both sides meaning anterior and posterior sides of the body or left and right sides of the body (DeWesse, & Nimphia, 2016). Unilateral movements/ exercise are movements that focus more on one side more than the other (DeWesse, & Nimphia, 2016). Unilateral movements can be performed where both sides are being utilized at the same time in different capacities like a Split squat, or performed individually like in a single leg calf raise (DeWesse, & Nimphia, 2016). A Split squat is an exercise where a majority of the exercise is focused on one leg and the other leg is used more for stability; a single leg calf raise is an exercise where the entire exercise is performed with one leg and the other leg is not active (DeWesse, & Nimphia, 2016). Examples of unilateral movements/ exercises are unilateral Romanian deadlifts, hip thrusts and pistol squats. Examples of bilateral movements /exercise are BS, deadlifts and bilateral jumping. These types of movements potentially could help strength coaches and athletes correct the asymmetry present in the human body (Bishop et al., 2017).

A bulk of the literature investigates asymmetries between limbs, and existence of asymmetry during execution of tasks, but does not investigate if the asymmetry between limbs has a measurable effect of performance (Bishop, Turner, & Read, 2017). Asymmetries are traditionally measured using strength and jumping tasks both unilaterally and bilaterally (Bishop, et al., 2017). Instinctively, strength coaches and athletes may think that a difference between limbs may negatively impact performances, but according to Bishop, Turner and Read (2017), that may not be the case. According to Bishop et al. (2017), asymmetries of approximately 6-8% in strength showed a negative association with jumping performances and sport-specific skills (i.e. kicking accuracy) (Bishop et al., 2017). However, when asymmetries are measured using unilateral jumping tasks, the results are unclear (Bishop et al., 2017). Asymmetries in peak power measured from unilateral countermovement jumps, or jump height measured with depth jumps showed that asymmetries of approximately 10%, negatively impacts change of direction performance (Bishop et al., 2017). In contrast to asymmetries in jump height and jump distance reported from multi-planar unilateral jump tests, results as high as 11.4% asymmetric had no impact on results of change of direction performance, or how well an athlete can change direction (Bishop et al., 2017). This makes drawing a conclusion about how asymmetry affects athletes difficult (Bishop et al., 2017). Also, Bishop et al. (2017) stated that similar discrepancies have been discovered in the literature about asymmetry and risk of injury. A threshold of 15% asymmetry classifies an athlete as high risk (Bell et al., 2014; Hewit, Cronin, & Hume, 2012; Impellizzeri et al., 2007). Asymmetries of less than 10% have been proposed as the target range for rehabilitation (Bishop et al., 2017).

Similar to the study of Bishop et al. (2017), this study investigated asymmetries in strength between left and right legs with regard to risk of injury, not how asymmetry in strength affects performance in various tasks. This study used the BS to measure asymmetry between left and right legs because the BS is one of the most popular bilateral lower body movements/ exercises (DeWesse, & Nimphia, 2016).

Asymmetry

According to Bishop et al. (2017), investigating asymmetry between left and right limbs has been a common area of research in recent years. The majority of the studies concluded simply the existence of asymmetry in various athletic tasks (Bishop et al., 2017). This study specifically investigated asymmetry in force output between the left and right lower limbs. There are multiple factors that could result in development of muscle strength imbalances and hence asymmetries in athletes, such as handedness, previous injury, and specific sport demands (Newton et al., 2006). Not only can muscular force output be asymmetric, but limb length also can be measured as asymmetric. According to McCaw and Bates (1991) there are three definitions to leg length inequality: a functional short leg, an anatomical short leg, and an environmental limb length inequality.

A functional short leg occurs after joint contracts causing an axial malalignment which then causes a rotated joint like the pelvis (McCaw & Bates, 1991). In the case of the pelvis, the foot on the short side was externally rotated and the longitudinal arch is collapsed, then the posterior iliac spine was higher on the short side while the anterior iliac spine is higher on the long side (McCaw & Bates, 1991).

An anatomical short leg occurs when there is a measurable difference in bone length (McCaw & Bates, 1991). The short limb often is compensated by a functional adaptation on the long side (McCaw & Bates, 1991). In the case of the lower body, the long leg may pronate to compensate for the short leg (McCaw & Bates, 1991).

Environmental limb length inequality occurs when, for example, a road runner continuously runs outside. Roads have a drainage slope to remove excess water, and this slope imposes a height difference between the limb on the curb side and the limb on the other side (McCaw & Bates, 1991). Over time this can lead to a difference in length between the two limbs.

A study done by Flanagan and Salem (2007) investigated the assumption that joint torques are equal between the left and right lower extremities by measuring bilateral differences when performing a BS. The study had 18 participants (men = 9, women = 9) who had at least one year of experience squatting (Flanagan & Salem, 2007). The participants performed three reps with 25%, 50%, 75%, and 100% of their 3-repetition max. Flanagan and Salem (2007) investigated: average joint moments at the hip, knee, and ankle; vertical ground reaction forces at each foot; center of pressure for each foot; and maximum flexion angle at the knee, hip and ankle. Center of pressure shifted forward for both feet as weight squatted increased; on average it was slightly farther forward on the left foot at all loads, and vertical ground reactions forces were higher for the left side (Flanagan & Salem, 2007). The study found differences of 12-17% side-to-side, with the left hip extensors, right quads, and left plantar flexors, on average, carrying more of the load (Flanagan & Salem, 2007). At first glance it would seem to indicate a difference of 15%, "high risk", but according to Flanagan and Salem (2007) leg length discrepancy or a movement restriction in a particular joint could also contribute to the difference (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007). The question that arises is, does symmetry matter for injury (Nuckols, 2015)? Some research says that asymmetry does increase risk of injury, others show that in a certain context asymmetry increases risk of injury, and others say that symmetry or asymmetry does not matter (Bell et al., 2014; Flanagan & Salem, 2007; Hewit et al., 2012; Impellizzeri et al., 2007; Nuckols, 2015). Some say that fixing asymmetry could potentially have a negative effect on an athlete before it has a positive effect (Bishop et al., 2017). For example, according to Bishop et al. (2017), in elite athletes decreasing asymmetry can throw off the level of motor control of an athlete while they are becoming accustomed to the increased level of strength, power or force.

According to Sato and Heise (2012), bilateral symmetry should not be assumed in experienced lifters. Research has shown that the same asymmetry found while quietly standing on force plates transferred to the BS (Sato & Heise, 2012). A hypothesis can be made that being asymmetric in force output was caused by skills training, strength training, and specific movement repetition (Newton et al., 2006). Newton et al. (2006) studied NCAA Division I softball players, whose ages ranged from 18 to 23 years, with at least one year of weight training experience. The 14 participants (age 20.2 ± 1.4 years, height 166 ± 6.7 cm, weight 67.2±9.1 kg) volunteered to undergo measures of average peak torque for isokinetic flexion and extension at 60 degrees per sec and 240 degrees per second (Newton et al., 2006). The warm-up consisted of one set of 8,6,4,3 repetitions at 60, 65, 70, 75% of 1RM, respectively, then three sets of one repetition at 80% of 1RM to parallel depth, with two minutes' rest between sets respectively (Newton et al., 2006). After the warm-up, the force plates were reset, and participants did three squats at 80% 1RM (Newton et al., 2006). A total of three sets were performed at that load, and the vertical ground reaction force (VGRF) for each foot was measured during both the concentric and eccentric phases of the movement (Newton et al., 2006). The average VGRF was recorded as the force output over the entire concentric phase (Newton et al., 2006).

In the squats, there was no significant difference between the right and left legs for either peak force (PF) or average velocity ground reaction force (AVGF), however, there was a difference between dominant (D) and non-dominant (ND) legs in PF and AVGF (Newton et al., 2006). In the vertical jumps, again there was no difference between right and left legs, however there was significant differences between D and ND legs during double leg vertical jump, and single leg vertical jump in PF and AVGF (Newton et al., 2006).

Irregularities in force output are present throughout human movement and can impair task performance (Doucet, Mettler, Griffin, & Spirduso, 2016). The main forms of dominance or preference are in the sagittal plane, meaning that there was a preference to use the left or the right-side of the body (Doucet et al., 2016). Lean body mass also shows correlation in lower body force asymmetry in jumping, and not only in exerting force but absorbing forces as well (Bell et al., 2014).

In a study by Simon and Ferris (2008), participants were measured on a leg press machine and results clearly demonstrated force imbalances persisted at both maximal and submaximal percentages of 1RM. Twelve subjects, seven males and five females (age 25 ± 3.0 years) participated in the study that was looking to determine if force asymmetry between lower limbs during bilateral force production results from a neural mechanism related to sense of effort (Simon & Ferris, 2008). Participants performed isometric lower limb extensions on a leg press exercise machine (Simon & Ferris, 2008). The participants laid down and placed their feet on vertical dual force platform with their shoulders firmly braced (Simon & Ferris, 2008). The leg press machine was locked with a mechanical stop so that the lower limbs of the participant were positioned in the middle of the range of motion (ROM) that was used to full lower limb extension (Simon & Ferris, 2008). All participants performed a pre-test which consisted of three bilateral isometric maximum voluntary contractions (MVC) with three minutes of rest between attempts; subjects were excluded if there was a difference of less than 10% (Simon & Ferris, 2008). Ten percent seems to be the bottom threshold where asymmetry can be considered negligible or not (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007; Simon & Ferris, 2008; Yoshioka, Nagano, Hay, & Fukashiro, 2010).

After the pre-test, Simon and Ferris. (2008) assessed the participant's MVC with three trials bilaterally, three trials of the right leg, and three trials of the left leg unilaterally with three minutes of rest between trials (Simon & Ferris, 2008). This was measured using electromyography electrodes, and the order of the tests were randomized (Simon & Ferris, 2008). At the completion of all nine trials, Simon and Ferris (2008) assessed which limb was the stronger limb by which limb had the higher peak force during the bilateral MVC (Simon & Ferris, 2008).

After ten minutes, Simon and Ferris (2008) looked to assess the participant's ability to match force in their lower limb with nine trials of force matching tasks. Participants exerted force equal to 20, 40, and 60% of the peak force from the weaker limb during the bilateral MVC (Simon & Ferris, 2008). The participant received visual feedback of the target force and the amount of force exerted by the strong limb throughout each trial (Simon & Ferris, 2008). Once the desired force was reach, then the participant was instructed to start applying force with the weaker limb, however no visual feedback was given (Simon & Ferris, 2008). Once the participant thought that they were pushing evenly, between the strong and weak leg, the participant verbally cued the experimenter (Simon & Ferris, 2008). Once the verbal cue was given the participant was instructed to hold the isometric contraction for three seconds before relaxing (Simon & Ferris, 2008). Participants performed three trials at each of the three force levels in a randomized order with three minutes of rest between trials (Simon & Ferris, 2008). Results showed that participants consistently and significantly produced less force in their weaker limb, but there was no significant difference between limbs during all force matching levels when normalized to their unilateral MVC force (Simon & Ferris, 2008). However, three separate ANOVAs were run, one at 20%, one at 40%, and one at 60% of the participants' MVC across both legs ($p = 0.0473$, $p = 0.0012$, and $p = 0.0007$ respectively). According to the findings of Simon and Ferris (2008), there was no significant difference between limbs at any of the force levels (20%, 40%, and 60%) ($p = 0.8490$). Biomechanical factors that determine muscle force are muscle length, shortening velocity, activation history, and current activation (Simon & Ferris, 2008). During the unilateral and bilateral contraction trials, Simon and Ferris (2008) controlled for three of the variables. All participants were tested laying down with their shoulders braced, same posture, joint angles, and muscle lengths remained the same (Simon & Ferris, 2008). Simon and Ferris (2008) kept shortening velocities at approximately zero cm/s or isometric, and before both trials all participants were rested so their activation history remained the same. The only variable left to influence muscle force was current activation neural drive (i.e. unilateral or bilateral maximum contraction) (Simon & Ferris, 2008). The result of similar peak forces between limbs during unilateral MVC shows the mechanical capabilities of each limb are equal. Asymmetry arose when activating the legs at the same time (Simon & Ferris, 2008). This means that regardless if people produce a maximal or a sub-maximal force, limb force asymmetry appears to be related to neural factors, and not mechanical capabilities between the limbs, according Simon and Ferris (2008).

Doucet et al. (2016) stated that irregularities in force, after peak-reduction (APR) output, are present throughout human movement and can impair abilities to complete sport-specific tasks performances. In conjunction with Sato and Heise (2012), who state that there was a bilateral asymmetry in the body, it can be concluded that APR was also bilaterally asymmetric in the body (Doucet et al., 2016; Sato & Heise, 2012). Doucet et al. (2016) studied 25 healthy adult volunteers (19 males, 6 females) aged 18-44 years. The participants were not athletically trained and were free of injury in the limbs that were tested (Doucet et al., 2016). The participants were divided into two groups: the ankle dorsiflexion (ADF) group (N = 16) and thumb adduction group (n=9) (Doucet et al., 2016). Doucet et al. (2016) investigated the large force discontinuity APR that appeared immediately after a peak in maximal effort ramp contractions. The participants were instructed to match force outputs as closely as possible to the target line of the ramp trajectory template displayed on a computer monitor by gradually increasing force from rest (Doucet et al., 2016). Doucet et al. (2016) investigated APR, which is the drop in force and recoil after a maximal force effort by a muscle. Doucet et al. (2016) then hypothesized that APR would be present across participants and would appear in both large and small muscle groups. It was also hypothesized that there would be a learning effect by which participants could reduce the APR amplitude (Doucet et al., 2016). A two-way ANOVA indicated that there was not a significant change in the number of APR's across successive ramp contraction in both large and small muscle groups, $F(1,24)$, $p > 0.05$. Doucet et al. (2016) did observe a trend for the presence of fewer APR's with successive ramp trials in both large and small muscle groups. Doucet et al. (2016) state that irregularities in force output are present throughout human movement and can impair tasks. If these irregularities are not only present in a unilateral movement, but are irregular in a bilateral movement, it can cause people to favor one side (Doucet et al., 2016; Perry, Carville, Smith, Rutherford, & Newham, 2007). This study investigated if sports-specific movements based on position on the field correlate with asymmetry measured by SA. That same asymmetry could be the reason that athletes favor a side of the body.

Researchers concluded that healthy trained individuals that were in the unequal weight distribution group when standing on force plates showed greater asymmetry in lower body force output during BS than the equal weight distribution group (Sato & Heise, 2012). Other studies have shown that there are asymmetries all throughout the human body, asymmetries from front to back, and side to side (Čović, 2015; Dessery et al., 2011; Hewit al., 2012; Hodges et al., 2011; Koh et al., 1993; Newton et al., 2006). Čović (2015) studied the asymmetry in the quadriceps to hamstring ratios by measuring the BS executed at different speeds. Dessery et al. (2011) investigated if limb preference influences gait initiation by looking at EMG data of the stance leg and the swing leg, and how asymmetry influences gait preference. Hewit et al. (2012) investigated asymmetry in multi-directional jumping task by measuring single leg and double leg CMJ on force plates. Hodges et al. (2011) studied the effects if fatigue bilaterally on ground reactive force during the BS, and its possible effect on asymmetry. Newton et al. (2012) investigated the asymmetry of the lower extremities by measuring different jumping tasks such as the five-hop test, single leg, and double leg vertical jumps. Asymmetry can be calculated in many different ways, and to be completely symmetric an athlete must be perfectly balanced in every way (Čović, 2015; Dessery et al., 2011; Hewit al., 2012; Hodges et al., 2011; Koh et al., 1993; Newton et al., 2006). This study investigated bilateral asymmetry between lower body limbs.

Interestingly, asymmetric power output tends to increase with age (Perry et al., 2007). Power outputs appear to be the most relevant measurement of fall risk in the elderly population (Perry et al., 2007). Researchers have concluded that aging affects muscular strength; sarcopenia, the loss of muscle mass, was evident when measuring all muscle groups combined - the fallers were consistently weaker than the non-fallers (Perry et al., 2007). There was no implicit research stating that sarcopenia effects asymmetry in the body, however, sarcopenia on top of a "high risk" could complicate life for the elderly. Research states that for "effective and safe control of the body", strength may not be the only issue, but the speed of the contraction could be an issue (Perry et al., 2007). Strength can be increased in the older population with strength training, but it was not certain that contractile speed can be increased (Perry et al., 2007). The fallers generated 85% of the force of the non-fallers and 79% of the power of the non-fallers (Perry et al., 2007). The steep reduction in power observed with age and difference in gender was expected and was consistent with other published data (Bassey & Short, 1990).

This study did not analyze the effects of aging on force output, but rather, analyzed the difference in force output between male and female participants.

If fallers could generate a higher percentage of total force compared to the non-fallers in a bilateral manner (this means exert a greater amount of force), then there would be less people falling. When a force was acting outside of an object's center of mass it creates a torque on the object, causing rotation (McGinnis, 2013). For example, when people are walking, their gait was broken down into three phases: when the stance leg is down and the swing leg is up, then the stance and swing leg are both down, and when the stance leg is up becoming the swing leg and the swing leg, now the stance leg, is down (Dessery et al., 2011). When the swing leg is up, the stance leg applies a force into the ground to create or continue locomotion (Dessery et al., 2011). In the next phase of walking or locomotion, that stance leg needs to exert the same amount of force to create a torque in the opposite direction to keep the center of mass upright. If the torques are not balanced, the center of mass may not get back to an upright position and then the person may fall. The more symmetric people are in their force output, the less likelihood there is of them falling, and injuring themselves. This study investigated a possible cause to asymmetric bilateral force output in Division II athletes, though through BS not gait analysis.

Performance and injuries have been related to functional asymmetries of the lower body, for example the different morphology in the lead and trail hips in golfers (Dickenson et al., 2016; Hodges et al., 2011; Luk, Winter, O'Neil, & Thompson, 2013). An asymmetry of up to 10% has been reported as having little or a non-significant difference than symmetrical and are likely not to be in risk of injury (Yoshioka et al., 2010). Yoshioka et al. (2010) looked at the maximal JH in two computer models, a model with perfect symmetry and a model with 10% asymmetry. The outcomes of the models were jump heights of 0.416 and .419m, respectively, a difference of less than one percent in total JH (Yoshioka et al., 2010). Yoshioka et al. (2010) state that ten percent asymmetry had a very small effect on jump height, but once asymmetry was greater than 10% then it has a greater effect on JH. It was important to note that Yoshiokat et al. (2010) set all asymmetries to 10% (right leg > left leg) across all muscles for simplicity knowing that in humans, asymmetries vary from muscle to muscle. The human leg is made up of many muscles and each muscle contracts at its own rate. This means that for every muscle in the leg there is a possibility of asymmetric balance between the pair of muscles in each lower limb (Yoshioka et al., 2010). Asymmetry greater than 15% should be considered atypical. According to Yoshioka et al. (2010), it can result in performance deficits, it is labeled as “high risk to injury”, and decisions should be made as to whether interventions need to be implemented that address the imbalance (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007). Documented injuries because of squatting form (i.e. muscular imbalances, or force output asymmetry), include muscle and ligament sprains, ruptured intervertebral discs, spondylolysis, and spondylolisthesis (Schoenfeld, 2010).

During an initial phase of the CMJ, the center of mass moved toward the stronger leg, then moved across the midline of the body to the weaker leg during the propulsion phase of the CMJ due to the VGRF of the strong leg that was greater than the weak leg (Yoshioka et al., 2010). Researchers classify the preference in limb usage when walking as stance leg and swing leg (Dessery et al., 2011). The stance leg is the leg where the CM shifts toward when the walking motion or the gait of a person is initiated. This shift in the CM allows the swing leg to move, thus creating motion (Dessery et al., 2011).

Yoshioka et al. (2010) also saw this same phenomenon in terms of work done by each leg in the two computer models. The total work (238.8 J) of the left leg (weaker leg) of the asymmetric model was less than the work of the right or left leg (246.2 J) in the symmetric model. However, the total work (257.7 J) of the strong (right) leg of the asymmetric model was higher than both the right and left leg of the symmetric models (Yoshioka et al., 2010). These results indicate that the strong (right) leg in the asymmetric model compensated for the strength discrepancy from right to left in the asymmetric model (Yoshioka et al., 2010). Similarly, to Sato and Heise's (2012) study when performing the BS, the group that had the greater VGRF asymmetry also had a greater angular displacement of the barbell. Angular displacement is the angle made between paths of motion; the path starting at the lowest part of the BS straight up, and the path actually traveled by the bar (Sato & Heise, 2012).

In addition to Sato and Heise (2012), Hewit et al. (2012) state that multi-directional leg strength/ power has to be assessed independently by its vector components. Assessing strength and asymmetry in one direction does not automatically translate to the other directions (Hewit et al., 2012). When performing a BS, depending on the participant's foot placement, the direction of the force exerted by the participant may not be completely vertical. Since performing a back squat can be interpreted differently depending on whom is performing the test, and foot placement may depend on biomechanical differences in each participant, there was not a general way to correct this in all participants (Braidot et al., 2007; Brandon et al., 2015; Čović, 2015; Gullett et al., 2009; Hagen et al., 1995; Hooper et al., 2014; Jakovljević et al., 2015; Lawrence & Carlson, 2015; McGinnis. 2011 Newton et al., 2006; Sato & Heise, 2012; Schwanbeck et al., 2009; Webster et al., 2015). This study only measured the vertical component of the force exerted to complete the BS. This study had the participants stand to perform the BS in a neutral stance that was comfortable for the participant. That means that the participant's feet were approximately shoulder width apart, even, and parallel to each other. This mean that the feet position cannot be staggered to hide a possible force output asymmetry.

Asymmetry was not only described as left to right, or vice versa, it can also be described as dominant to non-dominant. Newton et al. (2006) found significant differences when comparing dominant (D) to non-dominant (ND) legs for all tests except for single leg jumps, but no consistent differences were found in test performance when comparing left and right legs (Newton et al., 2006). Also, some D: ND ratios showed a correlation between test of squats, vertical jump, isokinetic testing, and five hop test as previously mentioned (Newton et al., 2006). This study did not measure D and ND force output, rather this study measured right and left force outputs when measuring SA. SA was specific in measuring the left-side over the right-side; if this study measured D to ND while using the SA to measure asymmetry, the results would not make sense because the values for the left and right lower limbs could switch from participant to participant.

Hewit et al. (2012) state that when the average symmetry index (ASI) magnitudes of all three force variables (vertical = 6.7%, horizontal = 8.0%, lateral = 8.4%) were grouped, no significant differences were detected between the three groups; however, the vertical force ASI (3.0%) was found to be significantly lower than the lateral force ASI (8.9%) when compared across directions. Power and distance ASI magnitudes also differed significantly in the horizontal and lateral directions, meaning that in the three components that Hewit et al. (2012) researched, the asymmetry was found to be the smallest in the vertical component compared to horizontal and lateral. Asymmetry in one direction does not necessarily predict asymmetry in another (Hewit et al., 2012; Yoshioka et al., 2010). This study investigated the levels of asymmetry in vertical lower body force output in a horizontal sense. Similarly, to what was mentioned earlier, while performing the BS, the lower body force output may be moving in two separate planes of motion. This study only measured the vertical component of the force due to the lack of ability to measure force in three planes of motion simultaneously. The difference between the statement of Hewit et al. (2012) and this study was that when an athlete changes direction, they tilt their axis and exert a vertical force to change direction. Using a single direction assessment to assess lower leg power asymmetries in players that perform powerful movements across multi-direction in competition does not provide a complete profile of asymmetries in each player (Hewit et al., 2012). This study measured asymmetries in a single direction in athletes that perform movements in multiple directions. However, by testing asymmetry in all three planes of motion one could then possibly compile a more complete asymmetry profile.

Reducing asymmetry

According to Bishop et al. (2017), reducing asymmetry can have both positive and negative effects on an athlete. According to the research, reducing asymmetry intuitively had a positive effect on an athlete's risk of injury, however the increased power, strength, or efficiency had a negative effect on an athlete's motor control until that athlete became accustomed to the new level of motor control (Bishop et al., 2017). Positively reducing asymmetry often reduces the risk of injury for athletes, which in return increases the longevity of an athlete's career (Bishop et al., 2017). However, for an elite athlete where any small change in motor control can be the difference between winning or losing, reducing asymmetry without allowing time to acclimate to the new level of motor control could negatively affect an athlete (Bishop et al., 2017).

Bishop et al. (2017) collected the entirety of research that was present in a meta-analysis about the reduction of asymmetries using training interventions (N=6). It was concluded that both unilateral and bilateral training could be considered effective at reducing asymmetry between left and right legs (Bishop et al., 2017). This study did not use a training intervention to reduce asymmetry; there was no training intervention at all. This study simply measured the presence of asymmetry when performing a BS and investigated if the origin of that asymmetry was from repetitive movements based on positioning within sport.

Asymmetry in lean mass

Lean mass was found to be a contributing factor to force and power output asymmetry in the lower body (Bell et al., 2014). The research of Bell et al. (2014) found that the average level of asymmetry in lean body mass was low and spanned between 1-3%; however, the range of asymmetry was important and demonstrates individual variability (Bell et al., 2014). The range of values for force asymmetry was approximately 25% (Bell et al., 2014). Ninety-five percent of the population were found to be between -11.79% (2.5th percentile) and 16.79% (97.5th percentile) (Bell et al., 2014). This means that 95% of the population that was tested in the study done by Bell et al. (2014) had an asymmetry score of close to 10%. Although not statistically significant, the findings of Bell et al. (2014) support that asymmetry in power negatively influences jumping performances. The findings of Bell et al. (2014) show that in individuals with asymmetry in power greater than ten percent have a performance deficit of 3.5 inches ($d > 0.80$), which is directly translatable and correctable by a SC professional (Bell et al., 2014). On a related note, the normative data showed that a small percentage of the Division I athletes are considered to be "high risk of injury" because asymmetry was greater than 15% (Bell et al., 2014).

Asymmetries of 15% were calculated because that was where the research has shown athletes can be deemed "high risk" for injury (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007). In the case of Bell et al. (2014), 15% asymmetry fell at the 1.25th percentile and the 96.75th percentile with seven participants (4%) having asymmetry greater than 15% and 34 (20%) having asymmetry greater than 10%. These were comparable to the results that were found in the study by Impellizzeri et al. (2007), who reported average force asymmetry of 0.8% with 15% of the data falling between the 2.5th and the 97.5th percentile.

Lean mass asymmetry does not entirely explain the above functional asymmetry; thus, improved understanding of this relationship was a logical and potentially important avenue to pursue. According to Bell et al. (2014), lean mass was related to joint torque and significantly contributes to energy absorption during landing. Lean mass explains a portion of the variance in power output during CMJ in children and older adults (Bell et al., 2014). This means that deficiencies in lower extremities' lean mass, particularly of the pelvis, thigh, and shank, may reduce the ability to produce force and power during jumping (Bell et al., 2014). Investigating lean mass asymmetry advances understanding of how asymmetry in the lower extremity contributes to injury and injury prevention (Bell et al., 2014). Bell et al. (2014) state that lean mass appears to be a contributing factor to force and power limb symmetry index (LSI), but a large percentage of the variance remained unexplained by the lean mass LSI. Bell et al. (2014) state that other factors that were not assessed in that study, but may be likely account for the remaining variance include neuromuscular control, muscular strength, muscle cross-sectional area and joint coordination. This means that lean mass helps with the absorption of energy when landing; if an athlete has less lean mass in one of the lower extremities, while participating in a bilateral landing activity such as landing a volleyball spike jump, then there was a risk of injury in that lower limb.

Asymmetry in lean mass was not only present in the athletic population; it was found in healthy individuals as well as the elderly population (Hodges et al., 2011; Perry et al., 2007). Functional asymmetries are present in healthy people during the BS and remain consistent, possibly even decreasing their difference in asymmetry in the BS (Hodges et al., 2011). Hodges et al. (2011) studied 17 healthy recreationally trained men and women and showed that there was no difference in the lower body force output during a BS when comparing right and left legs. This was explained because when Newton et al. (2006) analyzed the data there were enough data points that claimed left-side dominate, compared to data points that claimed to be right-side dominate. Of the fourteen subjects who were softball players that participated in Newton et al.'s (2006) study, all fourteen subjects stated that they were right-handed. However, only nine participants claimed to be right-handed batters, four were left-handed, and one claimed to be a switch hitter (Newton et al., 2006). When the data was analyzed, dominant (D) to non-dominant (ND) revealed a significant asymmetry (Newton et al., 2006). Newton et al. (2006) found a difference of up to six percent in force production, and in the double leg vertical jump height. Six percent asymmetry was not found to be at risk for injury due to a study that was previously mentioned, but 6% was enough to cause motion acting in one plane to act in multiple planes because of the torques being applied (Bell et al., 2014; McGinnis, 2013; Yoshioka et al. 2010).

According to Čović (2015) and Newton et al. (2006), depending on how a BS was executed, there was no difference in quadriceps-to-hamstring strength ratios. However, the hop-test done by Newton et al. (2006) was beneficial in discovering the asymmetries in subjects because the hop test identifies asymmetry in force output by the lean mass in the lower limbs individually. The five-hop test may provide a great field test for assessing the imbalance between legs (Newton et al., 2006). According to Newton et al. (2006) the five-hop test can give SC coaches the ability to quickly determine if an athlete is in need of a training program that focuses on unilateral exercises to isolate each side for strength balance improvement. The five-hop test was as followed: the participant begins with both feet together, then hops out on to one foot, then performs four consecutive hops on that same leg, landing on both feet on the fifth hop (Newton et al. 2006). Subjects are trying to maximize distance covered (Newton et al. 2006). If one foot exerts more force than the other, then that foot should travel further than the other. The study of Newton et al. (2006) attempted to give an understanding as to why a five-hop or the hop test were indicative of an asymmetry present in the lower limbs, by identifying if one of the lower limbs does indeed exert more force than the other while performing the BS. The research of Newton et al. (2006) used the BS exercise to expand the research on asymmetrical force output.

Asymmetry index

Quantifying biomechanical asymmetry was helpful in both research and clinical settings, but it was important that the measurement tool was vigorous enough to handle problems of reference values and inflation (Zifchock, Davis, Higginson, & Royer, 2008). Simple tests such as the BS and the CMJ have been deemed reliable and effective methods of assessing asymmetry in lower limbs (Bell et al., 2014; Hodges et al. 2011; Impellizzeri et al., 2007; Newton et al., 2006; Sato & Heise, 2012; Yoshioka et al, 2010). However, each researcher had a different method in stating, defining, and computing asymmetry in the lower limbs. With each method shown to be valid and have test-retest reliability, it was unclear which method and equation to use for any specific situation (Bishop et al., 2016).

Symmetry indices have been used during a multitude of symmetry research studies (Bell et al., 2014; Koh et al., 1993; Luk et al., 2013; Menzel et al., 2013; Simon & Ferris, 2008). A value of zero would show a perfect bilateral symmetry, whereas a positive indicates a right-side asymmetry and a negative value indicates a left-side asymmetry (Bell et al., 2014; Koh et al., 1993; Luk et al., 2013; Menzel et al., 2013). Two of the more popular symmetry indices in the research are the BI, and LSI (Bell et al., 2014; Koh et al., 1993; Luk et al., 2013; Menzel et al., 2013; Simon & Ferris, 2008). The LSI measures the unilateral force output of each lower limb against the other limb, meaning that the symmetry was considered from left to right (Bell et al., 2014; Bishop et al., 2016; Luk et al., 2013; Menzel et al., 2013). In a sport such as fencing, where right and left distinction is not important to the sport, but the distinction between D and ND is, this measure of asymmetry would not be the best measure (Bishop et al., 2016). This means the asymmetry from left to right in a left foot dominant fencer and a right foot dominant fencer gave a positive and a negative value respectively, even if the discrepancies are the same but opposite; but if you were to measure D to ND, left leg for one fencer and right leg for the other (and vice versa), then you would calculate the same value (Bishop et al., 2016). This means, in the example of the left foot dominant fencer, if the left foot dominant fencer had an asymmetry of 15% (the fencer's left foot had a 15% greater pushing force compared to the fencer's right foot), and in the example of the right foot dominant fencer, if the right foot dominant fencer had a asymmetry of 15% (the fencer's right foot has a 15% greater pushing force compared to the fencer's left foot), then both fencers would have an asymmetry of 15% D to ND (Bishop et al., 2016). However, one fencer has the asymmetry to the left and the other fencer has the asymmetry to the right.

The BI measures the bilateral force output against the unilateral force output of each lower limb combined (Bishop et al., 2016; Impellizzeri et al., 2007; Koh et al., 1993; Simon & Ferris, 2008). Impellizzeri et al. (2007) used the BI to measure the strength asymmetry during a CMJ (Bishop et al., 2016; Impellizzeri et al., 2007). The main limitation using the BI to measure asymmetry was the BI always puts the greater value first in the equation so that there was a positive value (Bishop et al., 2016). Over time that can cause issues if the asymmetry switches sides, since the value did not reflect that, the value remained positive (Bishop et al., 2016). This can happen if the value or percentage of asymmetry was lower than the value or percent error. For example, if results on trial one show that a participant was asymmetric to the left by 1%, then on trial two the results show that the participant was asymmetric to the right by 1%, the BI index, in both trials showed the participant was asymmetric by 1%, but it was not evident which side was one percent greater.

According to Bishop et al. (2016) and Zifchock et al. (2008), using a symmetry angle (SA) to calculate lower body asymmetric force output was the best method. The SA, compared to other symmetry equations, was much smaller and was immune to reference bias and overinflated scores (Bishop et al., 2016). The SA can be used to measure asymmetry in commonly used tests such as: a single leg CMJ, single leg hop test, isometric mid-thigh pulls, or exercises such as the BS where the only a measurement of force output was enough (Bishop et al., 2016). The SA was a measure of the relationship between discrete values measured from the right and left-side (Bishop et al., 2016; Zifchock et al., 2008). The SA relates to the angle formed when a right-side value was plotted against the left-side value: (X_{left}, X_{right}) (Bishop et al., 2016; Zifchock et al., 2008). Plotting two values creates angle α with the x-axis that is between $0 \leq \alpha \leq 90^\circ$. Subtracting α from the line of symmetry (45°) gives a new angle δ-α that is between $-45^\circ \leq (\delta-\alpha) \leq 45^\circ$. Dividing 45°-α by 90° leaves a value between $-\frac{1}{2} \leq \frac{\delta-\alpha}{90^\circ} \leq \frac{1}{2}$, then multiplying that value by 100 leaves a percentage that falls between $-50\% \leq SA \leq 50\%$ (see Figure 10).

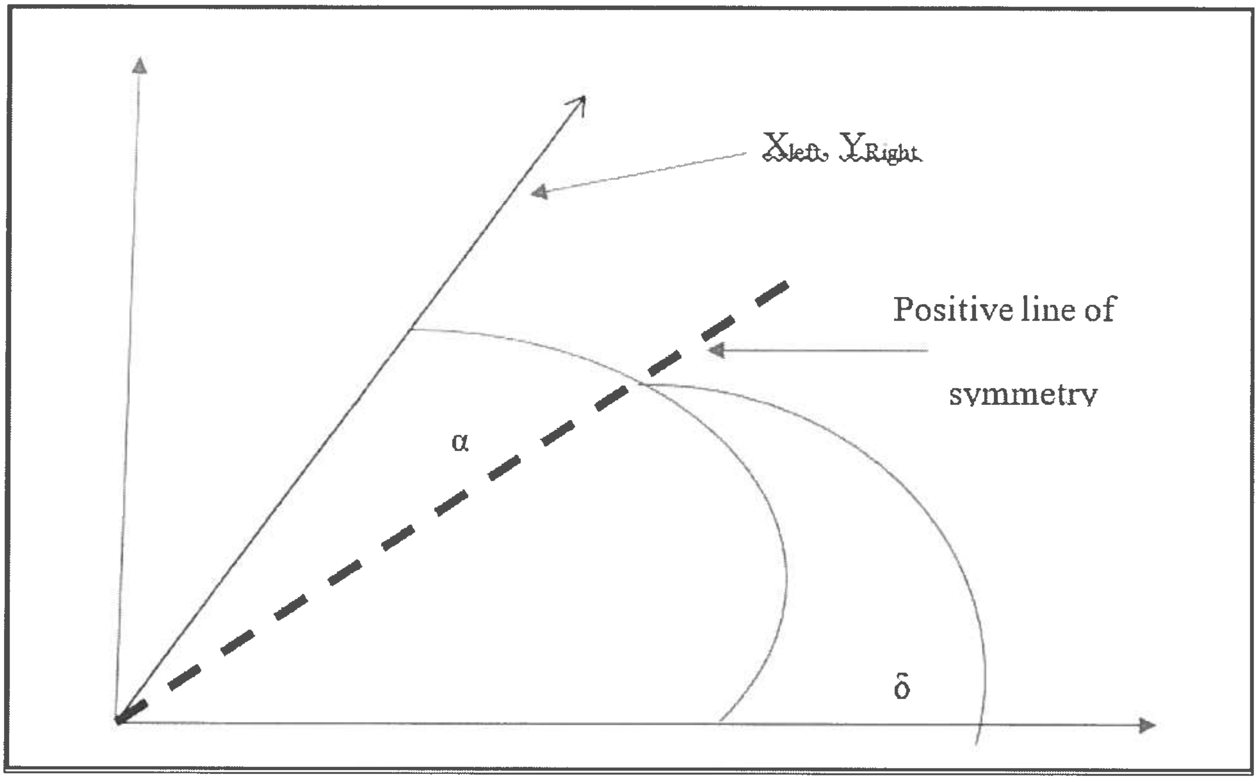

Figure 10. Symmetry Angle graph

The positive and negative lines of symmetry identify the symmetry between two positive values or two negative values (Bishop et al., 2016; Zifchock et al., 2008). The SA can be quantified as long as the values can be graphed and deviate a maximum of ± 90˚ from either line of symmetry (positive or negative) (Bishop et al., 2016; Zifchock et al., 2008) (see Figure 10).

The SA equation is as follows:

$$SA = \frac{45^{\circ} - arcTan(\frac{X_{left}}{X_{Right}})}{90^{\circ}} * 100\%$$

A SA value of 0% means perfect symmetry, while a value of 100% means that two values are equal in magnitude but opposite in direction (Bishop et al., 2016; Zifchock et al., 2008). This means that one force plate is registering a positive value while the other is registering a negative value, which can only happen if one of the force plates was attached to one of the legs and then pulled upward. In this study, there was no value greater than 50% (Bishop et al., 2016; Zifchock et al., 2008). A value of 50% means that on one leg the participant exerted value measured by the force plate, and on the other leg the force plate measured that the participant exerted a value of zero. This would be equivalent to the participant doing the same exercise but on one leg (see example below).

$$\text{Step 1: } SA = \frac{45^{\circ} - arcTan(\frac{0}{1000})}{90^{\circ}} * 100\%$$

$$\text{Step 2: } SA = \frac{45^{\circ} - 0}{90^{\circ}} * 100\%$$

$$\text{Step 3: } SA = .5 * 100\% = 50\%$$

Another reason why the SA was viewed to be superior to other index scores, was the need not to set a reference side (Bishop et al., 2016; Zifchock et al., 2008). For example, consider the case of two participants who both show a difference of 10%, but one participant is 10% greater on the left and the other participant was 10% greater on the right (Bishop et al., 2016; Zifchock et al., 2008). Putting these values into a standard symmetry index (SI) outputs as follows:

$$\text{Right Larger: } SI = \frac{ABS((X_{Left} - X_{Right}))}{X_{Right}} * 100\%$$

$$= \frac{ABS((1000 - 1100))}{1100} * 100\% = 9.09\%$$

$$\text{Left Larger: } SI = \frac{ABS((X_{Left} - X_{Right}))}{X_{Right}} * 100\%$$

$$= \frac{ABS((1100 - 1000))}{1000} * 100\% = 10\%$$

Therefore, the SI values are different but the asymmetry was approximately the same. If the same 10% asymmetry is used in the SA equation, one value is positive and one value is negative.

$$\text{Left larger } Step\ 1 := \left(arcTan\left[\frac{1100}{1000}\right]\right) = 47.73^{\circ}$$

$$Step\ 2 := \left(\frac{[45^{\circ} - 47.73^{\circ}]}{90^{\circ}}\right) * 100 = -3.03\%$$

$$\text{Right larger } Step\ 1 := \left(arcTan\left[\frac{1000}{1100}\right]\right) = 42.27^{\circ}$$

$$Step\ 2 := \left(\frac{[45^{\circ} - 42.27^{\circ}]}{90^{\circ}}\right) * 100 = 3.03\%$$

If the arctan function gives a number greater than 45 degrees, or when converted to negative value, that means that the participant has a greater force output to the left. Similarly, if the arctan was less than 45 degrees or when converted positive, the participant has a greater force output on the right. This study not only looked to see if there is a correlation between repetitive sports movement in the outcome of SA, but if there was a higher SA in males vs females.

Gender differences

Researchers have shown that with both men and women executing a BS, the knee and hip angles during the latter part of a high repetition set increase (Hooper et al., 2014). Hooper et al. (2014) studied 12 men and 13 women with at least six months of resistance training experience. A two-dimensional analysis was performed where the subjects' knee and hip angles were recorded through all 55 total repetitions done during the extreme conditioning protocol (ECP). Hooper et al. (2014) found that in both men and women, knee and hip angle changed significantly: for the men knee angle (early 97.4 ± 6.8 vs. late 90.4 ± 5.6) and hip angle (early

86.7 ± 15.9 vs. late 116.8 ± 7.2): and for the women knee angle (early 103.9 ± 8.1 vs. late 91.7 ± 10.0) and hip angle (early 87.6 ± 9.1 vs. late 101.5 ± 8.6). This indicated that between men and women, the change in angle in the knee and ankle joint was not due to gender. The change in angle was due to the self-preservation of the participants (Hooper et al. 2014). Self-preservation is when a participant changes his or her technique slightly in order to save energy to complete the required number of reps (Hooper et al., 2014). This agrees with the research of Hagen et al. (1995), stating that if the technique changed to more of a stoop, there was less flexion at the knee, allowing for the CM to move anterior to the knee, which results in less work for the knee extensor muscles (see Figure 11).

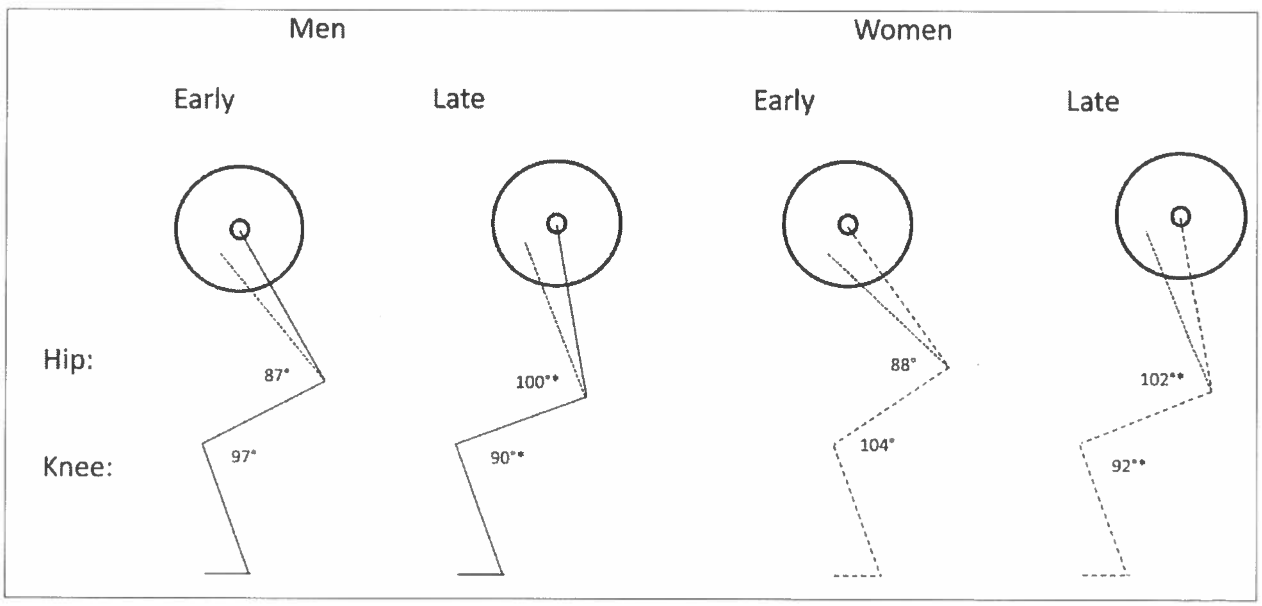

Figure 11. Change in squat during extreme conditioning protocol (Hooper et al., 2014)

If the BS form was changed to more of a stoop technique versus a squat, there was less flexion in the knee, allowing for the center of mass (CM) to move more anterior to the knee; this means there was less work required for the knee extensor muscles, thus decreasing performance (see Figure 9) (Hagen et al., 1995). However, Hooper et al. (2014) state that women may be more sensitive to technique changes than men; meaning that when performing the BS during an extreme conditioning protocol (ECP) women showed significantly less knee flexion and significantly lower hip angle than men (Hooper et al. 2014).

When talking about the relationship between strength and changes in JH and vertical stiffness, Witmer, Davis, and Moir (2010) showed there was a large negative relationship between the absolute change in JH and normalized 1RM in men, while women had a small positive relationship. This could be explained by the increase of the time spent in the amortization phase of stretch shorting cycle (SSC) when women are squatting (Witmer et al., 2010). The extra time spent in the amortization phase results in a loss of stored elastic energy in the form of heat (Witmer et al., 2010). Witmer et al. (2010) studied the effects of BS on JH on 12 men and women in a post-activation potentiation (PAP) study. PAP was the idea that adding resistance exercises in an athlete's warm-up can have an acute positive effect on an athlete's performance (Witmer et al., 2010). The protocol of Witmer et al. (2010) showed that each group participated in both the potentiation, the group that performed the BS, and the control group, that did not perform BS, in a cross-over design. Witmer et al.'s (2010) potentiation consisted of three sets of BSs of 5 reps at 30% of 1RM, 4 reps at 50% of 1RM, and 3 reps at 70% of 1RM, while the non- potentiation group walked to the lab before doing the CMJs. The results showed that the control group had a higher JH in both men and women, and that there was no difference in JH in the BS potentiation group, between men and women. This means that there was no difference between men and women when it comes to this particular PAP protocol. This study did not have participants perform the three sets of one rep at 70% of 1RM similar to Witmer et al. (2010); the participants only performed the BS.

One of the most interesting factors when it came to power discrepancy was overall strength (Bailey, Bazyler, Chiang, Sato, & Stone, 2014). According to Bailey et al. (2014) of the two groups, weak and strong, the weak mean values correlated. Weaker athletes had larger asymmetry in the isometric mid-thigh pull for the men while neither group (weak or strong) on the women's side showed significant correlation (Bailey et al., 2014). The same variables produced different correlation results in the stronger males (Bailey et al., 2014). The correlations that were found significant in the weak group became no longer significant, vanished, or reversed directions in the strong group (Bailey et al., 2014). Again, this was not specifically asymmetry in the bilateral sense, but the results of Bailey et al. (2014) show that there was a difference between male and females when specifically talking about the asymmetry shift from weaker to stronger subjects (Bailey et al., 2014). Bailey et al. (2014) mentioned that it was not clear why the relationship with female athletes at different strength levels was different than the relationship with males, but they state that further research needs to be done to understand this difference.

According to the study of Bassey and Short (1990), of the total participants (N = 66, male = 15, female = 51) which were split up into four groups, results showed that young men were more powerful than the young women groups. Also, a highly significant decrement occurred with age for both genders. Bassey and Short (1990) investigated a new method, and its reliability, feasibility and validity in measuring power output in single leg extension.

Another study done by Bailey, Sato, Burnett and Stone (2015) found bilateral strength asymmetry seemed to be similar between male and female athletes of varying sports backgrounds. However, that bilateral strength asymmetry was not found to be the same when samples were split based on strength levels. Bailey et al. (2015) studied 63 NCAA Division I athletes (male N = 31, female N = 32, age 18-32 yrs.) from various sports that included baseball, men's and women's golf, tennis, soccer, softball, and volleyball, for weight distribution and jumping test. One hundred and twenty-nine athletes (participating in the same sports, male N = 64, female N = 65) participated in bilateral strength asymmetry assessment (Bailey et al., 2015). Athletes performed all tests on the same day, which included weight distributed, squat jumps (SJ), and CMJs (Bailey et al., 2015).

Before any testing, athletes completed a standard warm-up that consisted of 25 jumping jacks, a set of five repetitions of dynamic mid-thigh pull with an unloaded 20-kg bar, and three sets of five repetitions with either 60 kg or 40 kg, male and females respectively (Bailey et al., 2015). Jumps were performed on dual force plates, and data was sampled at 1000 Hz (Bailey et al., 2015). All athletes went through familiarization trials for each jump at 50 and 75%of perceived maximal effort without arm swing (Bailey et al., 2015). During the squat jump trial, the athlete was instructed to step on to the force plates and stand still for two to three seconds to allow for collecting force data from each force plate for weight distribution (Bailey et al., 2015).

During the squat jumping the athlete began the test with a 90-degree bend at the knee joint, which was measured by a goniometer and held that position for three seconds before executing the SJ (Bailey et al., 2015). While performing the CMJ athletes descended to a level that they found to be sufficient to perform the CMJ (Bailey et al., 2015). A total of eight jumps were performed, two SJ with zero and 20 kg, and two CMJ with zero and 20 kg, in a randomized order (Bailey et al., 2015). Bailey et al. (2015) used a custom power rack to measure bilateral strength asymmetry when performing an isometric mid-thigh pull. The isometric mid-thigh pull was performed on dual force plates, and data was sampled at 1000 HZ (Bailey et al., 2015). The height of the bar was set for each individual participant; the bar was set at a height that required approximately 125° ± 5° bend of the participant's knee angle, and the athlete's hand position was secured with hand straps and athletic tape to reduce the risk of grip loss (Bailey et al., 2015). Athletes went through two familiarization and warm-up trials at 50% and 75% of the perceived maximum effort (Bailey et al., 2015). For the three tests, the average of the two trials were used for data analysis as long as there was no observed countermovement or countermovement less than 200 N (Bailey et al., 2015).

LabVIEW computer program (version 12.0, National Instruments Co, Austin, TX, USA) was custom designed to be used in collection and analysis of kinetic data during the bilateral strength assessment (Bailey et al., 2015). Kinetic data obtained in the weight distribution, SJ, CMJ, and isometric mid-thigh pull were analyzed to produce both separate and summated values from the dual force plates (Bailey et al., 2015). Magnitude of asymmetry was calculated with a symmetry index (SI) score used by Sato and Heise in 2012 (Bailey et al., 2015): SI score = (larger value- smaller value)/ (total value) * 100 where a value of zero means perfect symmetry (Bailey et al., 2015). When the participants were divided into strong and weak groups, statistical differences were observed in isometric peak force (p = .03; d = 0.82; Strong group SI 4.72 ± 0.07; Weak group 9.41 ± 0.13) and rate of force developed (p = 0.19; d = 0.90; Strong group SI 5.52 ± 0.45; Weak group 12.85 ± 0.70) (Bailey et al. 2015). According to Bailey et al. (2015), that bilateral strength asymmetry difference may indicate that absolute strength was a more important factor than gender difference during isometric testing. However, this study investigated if specific sports movement factors into asymmetry in athletes as well.

Sports

In sports that require an athlete to stay on a specific side of the field, an athlete tended to perform a sport-specific movement on one side of his or her body more than the other side. In every sport, there are specific movements that are defining to that specific sport. For example, in soccer, kicking defines the sports more than any other of its sports movements, in volleyball it was jump spiking, and in baseball and softball it was the throwing motion (Lees, Asai, Anderson, Nunome, & Sterzing, 2010; Plummer & Oliver, 2014; Wagner, Tilp, Duvillard, & Mueller, 2009). Sports specific movements may cause an asymmetry in an athlete because of it repetitive nature on a specific side of the body. Side to side asymmetries were recorded in sports such as soccer and softball players according to Nuckols (2015). The primary investigator was assuming that in sports that have a specification to the position on the field (i.e. right, left or center), the athletes playing that position spent a majority of the time there (i.e. right, left, or center). This study investigated if there was a relationship between sports specific movements because of the specific third of the field that an athlete plays on and SA. Also, this study investigated if there was a difference in SA between different sports and gender. Figure 12 shows four different soccer positions displaced over 45 minutes during a soccer match (from left to right: goalkeeper, left defender, left midfielder and a left attacker) (Dargiewicz & Erdmann, 2007).

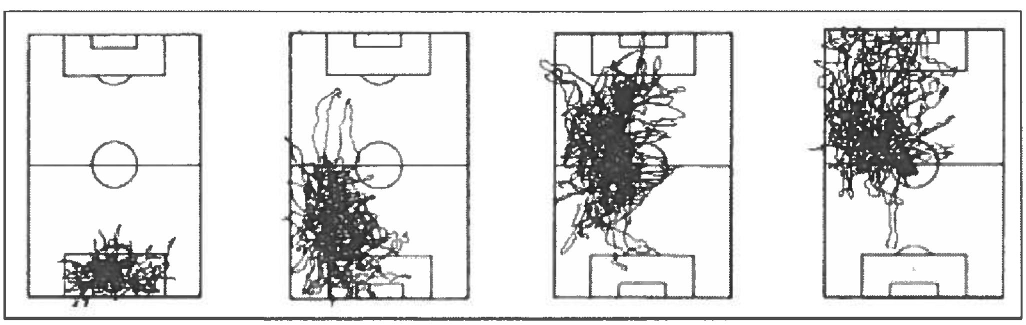

Figure 12. Player displacement during soccer game (Dargiewicz & Erdmann, 2007).

From the analysis shown in Figure 12, it was clear that in soccer an athlete the plays on the left-side of the field stays on the left for the majority of the game. The primary investigator made an assumption that a player positioned on the left part of the field (i.e. left defense) stayed on the left third of the field. This means the field was broken down into three equal thirds that have corresponding position labels (i.e., left, center, right, or LCR).

Soccer

In the sport of soccer, kicking was the defining action, and it can be broken down into various aspects including: the approach, how the pelvis was supported, the kicking leg, and the flight of the ball (Lees, et al., 2010). According to the research, when it comes to the approach, skilled players prefer to run up at an approximate angle of 43 degrees at a distance that requires two to four steps before striking the ball (Kellis & Katis, 2007; Lees et al., 2010). For example, in an athlete who wants to kick the soccer ball with his or her right foot, the first step was with the right foot followed by the left then kicking the ball with the right foot (Kellis & Katis, 2007).

Lees, Kershaw, and Moura (2005) studied eight experienced male soccer players (mean age 20.6 years; mean height 1.799 m; mean body mass 72.8 kg), who were asked to perform five maximal instep kicks of a stationary ball, while wearing 16 reflective markers. These reflective markers were placed on the player's joints that defined a 12-segment biomechanical model, and captured using a six-camera set-up located in an indoor lab (Lees et al., 2005). The locations of these markers were on the knee, ankle, hip, and trunk, allowing the researchers to calculate joint angles (Lees et al., 2005). In the study of Lees et al. (2005), correlation values were significant if greater than 0.4, which included a Bonferroni adjustment for multiple use of data sets. The results of Lees et al. (2005) showed that ball speed correlated with approach speed (0.659 m/s), peak hip speed (0.652 m/s), peak knee speed (0.703 m/s), and the length of the last stride (0.419 m/s). This means that the faster the kicking limb was swung the faster the ball should move, which agrees with Newton's laws of momentum (McGinnis, 2013). If an athlete was continuously kicking the ball with one limb vs. the other, an asymmetry could develop because of the constant use of the same limb as the stance leg (Dessery et al., 2011). In this study, the primary investigator investigated if sports-specific movements create imbalances in lower body force output. For example, soccer athletes repeatedly kick a soccer ball with one side of their body, and the position played keeps them on one side of the field for a majority of the game, thus a physical asymmetric force output could possibly develop.

Positioning

Erdmann and Dargiewicz (2007) investigated three groups of soccer athletes belonging to different levels of development: (A) international players playing at "A" level matches, (B) international players playing at Olympic level matches, and (C) international players playing at U-16 level matches. The paper by Erdmann and Dargiewicz (2007) analyzed matches between Poland – England (A level), Poland - Italy (A level), Poland – Norway (Olympic level), and Poland – Germany (U-16 level). Kinematic data such as displacement (m), time (s), velocity (m/s), and acceleration (m/s^2) were measured by Erdmann and Dargiewicz (2007). Erdmann and Dargiewicz (2007) stated that a camera with a 130° lens was used to measure kinematic data of all players at all times during a match. The data processing of the recorded soccer games was done using a BANAL computer program (Erdmann & Dargiewicz, 2007). The analysis showed that a left defender stays on the left-side of the field for a majority of the time (see Figure 13). In this study the primary investigator investigated if there was a correlation between SA and sports-specific movements because of position on the field.

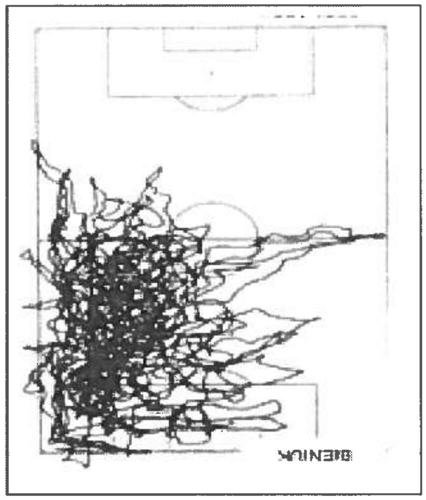

Figure 13. Left defender displacement during a soccer match from (Erdmann & Dargiewicz, 2007).

Volleyball

Jump height was a defining variable in volleyball performance. According Wagner et al. (2009), there are several mechanisms such as counter movements and arm swing to increase jumping height. In volleyball, the spike jump can be broken down into three different phases: the approach phase, the take-off phase, and the attack phase (Wagner et al., 2009). The approach phase of a right-handed athlete was defined between the left foot take-off and finishes with ground contact of both feet right before the vertical jump (see Figure 14) (Wagner et al., 2009).

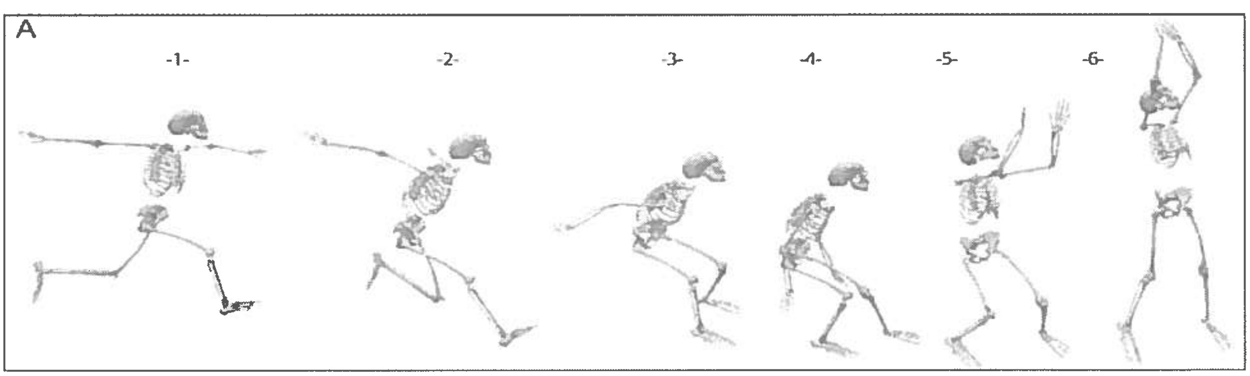

Figure 14. Phase two of volleyball spike jump (Wagner et al., 2009).

Wagner et al. (2009) studied 16 male volleyball players who participated in the first and second league of the Austrian National competition (mean age: 24.1 ± 3.7 years; body height: 1.88 ± 0.06 m; body mass: 81.8 ± 7.1 kg; training age experience: 10.3 ± 4.1 years); all participants were right-handed. Wagner et al. (2009) measured the JH of the CMJ and the spike jump of the sixteen participants on a force platform. The results of Wagner et al. (2009) showed that there was significant correlation for JH of the spike jump with the: maximal horizontal velocity of the CM ($r = 0.71$, $p = 0.00$), minimum height of CM ($r = -0.68$, $p = 0.00$), jump height for CMJ ($r = 0.66$, $p = 0.01$), and spike jump ($r = 0.74$, $p = 0.00$). This mean that the faster the CM was moving horizontally, the higher the jump height; similarly, the lower the CM was before jumping the higher the recorded jump height. Wagner et al. (2009) concluded that standard jumping tests are useful in volleyball- specific test batteries as they generate objective results that are related to the spike jump. Interestingly, although the spike jump was executed with both legs, the data of Wagner et al. (2009) revealed the asymmetries of the jump movement. This study investigated not only if volleyball had a different SA than soccer, baseball or softball, but investigated if position on the court affects the SA measured in volleyball players.

According to Kugler et al. (1996), in overhead sports such as volleyball and baseball shoulder problems are common among highly skilled athletes in their attacking arm (the arm they swing with or throw with) and not in their non-attacking arm. Kugler et al. (1996) studied 45 participants that were divided into three groups. Group one was made up of 15 volleyball hitters that had shoulder pain (male = 10, female = 5, age = 24.8 ± 2.9 yrs., weight = 74.2 ± 11.9 kg, height = 182.7 ± 90 cm). Group two was made up of 15 volleyball hitters that had no shoulder pain (male = 12, female = 3, age = 25.1 ± 3.1 yrs., weight = 76.6 ± 9.0 kg, height

= 182.7 ± 9.0 cm). Group three was made up of 15 recreational athletes (male = 12, female = 3, age = 24.0 ± 3.1 yrs., weight = 74.5 ± 13.3 kg, height = 178.6 ± 9.4). The participants underwent an clinical examination that concentrated on shoulder depression, tender points, crepitation, upper arm girth, arm length, active and passive range of motion, and muscle strength (Kugler et al., 1996). The results of this study showed that all 30 volleyball players had depression of the playing shoulder of 1-3 cm (Kugler et al., 1996). There was no significant difference in flexibility, and upper arm girth in the attacking arm was increased about 1 cm in all groups from playing to non-playing arm (Kugler et al., 1996). Kugler et al. (1996) concluded that the mechanism that caused the changes was unclear but suggest that players that do not have shoulder pain, and especially the players that have shoulder pain, should stretch the shortened muscles and strengthen scapular fixation muscles (Kugler et al., 1996). This study did not look into the differences of the shoulder in volleyball players but the asymmetric force output of their lower limbs.

Baseball/Softball

Plummer and Oliver (2014) state that only a few studies have examined the mechanics of catchers throwing to second base. Since the catcher throwing a baseball to the second baseman standing on second base was in the center of the field, the primary investigator assumed that these players who are centrally located on the field was more symmetric than the other players positioned non- centrally. This was because these players that are centrally located have a better chance of reacting to sports plays (executing sports-specific movements) equally to their left and their right-sides.

Throwing was one of the defining motions in baseball and softball. The throwing motion can be broken down into four phases: foot contact, maximum external rotation, ball release, and maximum internal rotation (Plummer & Oliver, 2014). When a catcher throws the ball, the catcher draws energy from his or her lower extremities (lower limbs, pelvis, and trunk), and that energy is then transferred distally to the shoulder, elbow, wrist, hand, and then to the ball upon release (Plummer & Oliver, 2014). The stability of the pelvis is fundamentally supplied by the muscles surrounding the lumbar and the hip region, specifically through activation of the gluteal muscle group (Plummer & Oliver, 2014). The gluteal muscle group acts to stabilize the torso over a leg that was planted and allows for transference of power during the forward leg movements (Plummer & Oliver, 2014).

Plummer and Oliver (2014) studied 42 young baseball and softball catchers (age: 14.74 ± 4.07 years; height: 161.85 ± 15.24 cm; weight: 63.38 ± 19.98 kg). When divided by gender the demographic data was as follows: 22 male baseball catchers (age: 12.77 ± 3.48 years; height: 159.35 ± 18.97 cm; weight: 57.21 ± 22.96 kg) and 20 female softball catchers (age: 16.90 ± 3.60 years; height: 166.70 ± 8.57 cm; weight: 70.16 ± 13.65 kg) participated (Plummer & Oliver, 2014). Participants were fitted with EMG electrodes placed on the medial aspect of the torso at C7, medial aspect of the pelvis at S1; two electrodes were placed bilaterally distal/posterior aspects of the upper arm, two electrodes were placed on the bilateral distal/posterior aspects of the forearm, and two electrodes bilateral distal/ proximal posterior aspect of the upper leg (Plummer & Oliver, 2014). Surface gluteal EMG results showed a moderate negative correlation between stride leg gluteus maximus EMG activity and pelvis rotation at foot contact ($r = -0.31$, $r^2 = 0.10$, $p = 0.05$) (Plummer & Oliver, 2014). Drive leg gluteus maximus EMG activity and trunk flexion has a moderate positive relationship at foot contact ($r = 0.33$, $r^2 = 0.11$, $p = 0.04$) (Plummer & Oliver, 2014). The results from Plummer and Oliver were found in both boys and girls. This means that the gluteus muscle acts as a stabilizer to the pelvis and forms an anchor point for the trunk flexors on that one side. Since baseball and softball players usually only throw with the dominant hand, repetitive throwing can possibly cause an imbalance in the muscles that are used to stabilize the pelvis and the muscles that flex the trunk for all positions on the field (Plummer & Oliver, 2014). The research of Plummer and Oliver (2014) was not specifically about athletes that play on the left or the right of the field, but the primary investigator investigated the difference in SA between thirds of the field and their corresponding positions since all positions throw the ball in some fashion (pitching or throwing). The pitching motion is a more specific throwing motion, with the main difference being the specific foot placement during the pitching motion (Plummer & Oliver, 2014).

The baseball pitching motion can be broken down into eight progressive positions that can be analyzed (Kibler, Wilkes, & Sciascia, 2013). These are the trunk, control over the back leg, hand pronation on top of the ball in cocking, front leg directly toward home plate, arm cocking-scapular retraction/arm in the scapular plane, high elbow above shoulder, and long axis rotation coupled with shoulder internal rotation/forearm pronation at ball release (see Figure 15).

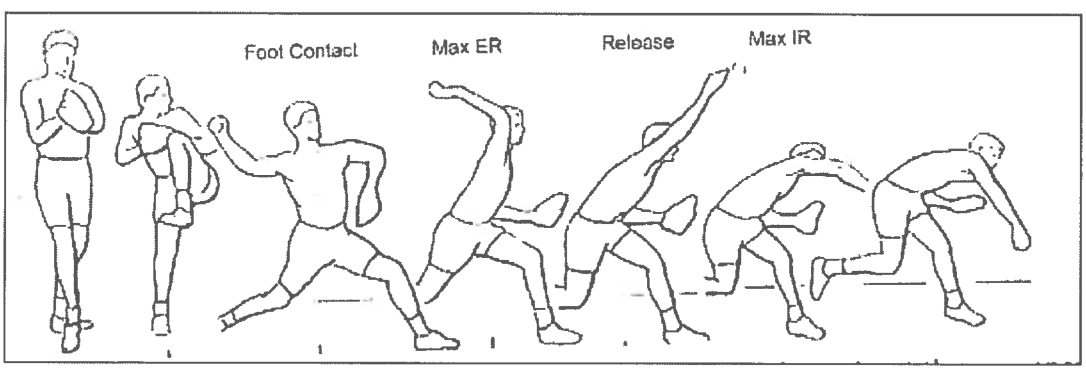

Figure 15. Pitching motion (Kibler et al., 2013).

This study did not study the throwing motion of a baseball or a softball player since it was the same for all baseball athletes with exceptions to the pitcher and the catcher. However, the direction in which the athlete has to move to field a ball, prior to throwing the ball, may differ for each athlete depending on the position played on the field. This study investigated if there was a correlation to SA and position on the field.

Jumpers and power lifters

Muscular strength was a crucial component for success in athletic performance (Luk et al., 2013). Athletic sports movements require a wide variety of motor demands and strength levels, depending on the movements of the sport, and whether it was comprised of bilateral and/or unilateral movements (Luk et al., 2013). Sport-specific demands between power lifters (PL) and jumpers (J) may contribute to the presence of asymmetry in lower body force output (Luk et al., 2013). Luk et al. (2013) investigated the bilateral and unilateral force production difference between PL, who perform bilateral movements, and field jumpers, who perform unilateral movements. Luk et al. (2013) studied 19 participants (PL, n=11; J, n=8; PL, competed in competitive power lifting, were Division III field jumpers), who did five different no arm swing jumps in a randomized order: a double leg jump; dominant leg-specified double-leg jump; non-dominant leg-specified double-leg jump; dominant leg-specified single-leg jump; non-dominant leg-specified single-leg jump. According to the results of Luk et al. (2013), jumpers had a higher asymmetry score than the power lifters; asymmetry was measured using a limb symmetry index (LSI) which was mentioned previously (see Figure 16). Since jumping in field events was a unilateral movement, these participants have developed more of an asymmetry in their lower body than the PL.

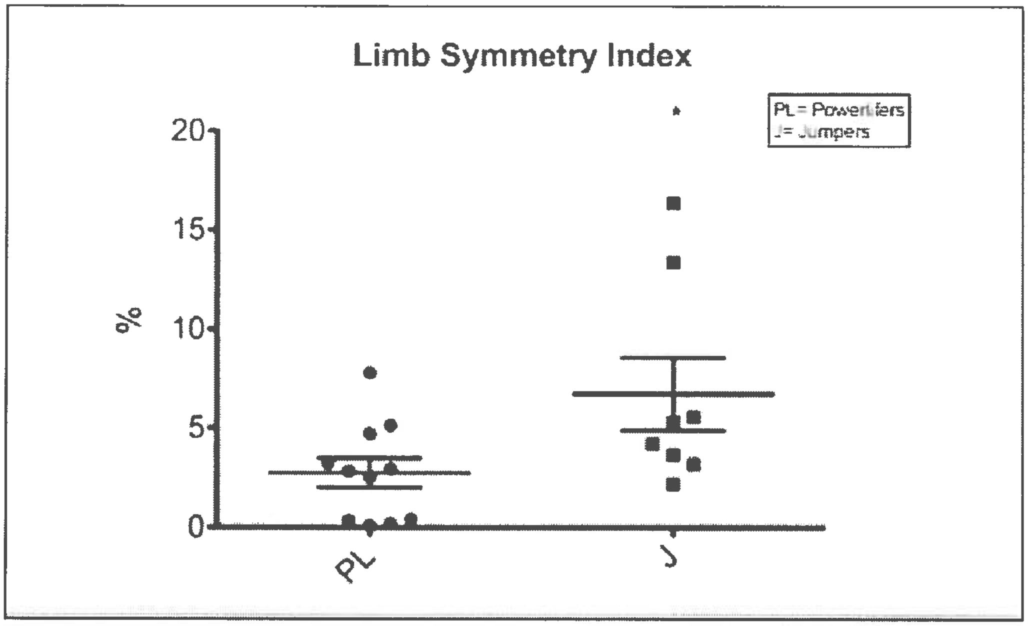

Figure 16. Asymmetry score between power lifters and jumpers (Luk et al., 2013).

Muscular and neuromuscular adaptations to the sport-specific demands may be the reason for the asymmetric lower body force production in athletes (Luk et al., 2013). For example, a shortstop in baseball throws more often to their left (towards first base) than to their right (towards third base) because there was more action at first base. During every at bat, if the batter can hit the ball into fair territory (without the baseball being caught), then the batter attempts to advance themselves to first base or beyond. Therefore, the shortstop always has an opportunity to throw the ball to first base to throw out a base runner. There was not always an opportunity to throw out a base runner at second or third base if that base runner did not successfully make it to first or second base, respectively, on the previous at bat. A shortstop may be neuromuscular and muscularly more efficient in the throwing motion to his or her left than to the right because of the number of throws that are made to the left-side.

Limb preference has also been associated with injury risk in athletes (Luk et al., 2013).

According to Luk et al. (2013), strength testing was not a typical screen for athletes, but neglecting the existence of limb asymmetry may predispose athletes to poorer performance or injury. This study looked to see if asymmetry can be predicted by position on the field, so then these athletes can be screened and action can be taken to prevent injury.

Summary

The ability to quantify lower body force output asymmetry in athletes is very beneficial to SC specialists and coaches alike. It gives athletes and coaches a place to start the journey in producing a more balanced and complete athlete, while understanding the possible correlation between the positions on the field, the asymmetric force that was outputted in the BS, and how that asymmetrical force output can affect physical performance. Understanding how the position on the field relates to asymmetric force output can help assess and pre-screen for "high risk" of injury athletes. This literature review covers asymmetry in: multiple types of jumps, gender, and fatigue, but does not investigate lower body asymmetry during the BS exercise. Multiple studies discussed in this literature review use the BS to aid in finding results of total strength gain, rate of force produced, activation of stabilizing musculature, and the possible ways BS correlates to speed, strength, and agility tests (Braidot et al., 2007; Brandon et al., 2015; Čović, 2015; Gullett et al., 2009; Hagen, et al. 1995; Hodges et al., 2011; Hooper et al., 2014; Jakovljević et al., 2015; Lawrence & Carlson, 2015; Newton et al., 2006; Ojeda et al.,2016; Schoenfeld, 2010; Schwanbeck et al., 2009; Webster et al., 2015; Witmer et al., 2010). Similarly, multiple studies use the CMJ or a variation of the CMJ to test for asymmetry in athletes and athletic performance (Bell et al., 2014; Brandon et al., 2015; Cormie et al., 2009; Driss et al., 2001; Hewit et al., 2012; Impellizzeri et al., 2007; Jakobsen et al., 2012; Luk et al., 2013; Menzel et al., 2013; Witmer et al., 2010). However, to the best of this researcher's knowledge there was a lack of research to date testing the asymmetry using the BS. To date a majority of research on asymmetry was tested while performing a jumping task, which isn't always applicable to contact sports. In contact sports, athletes are attempting to perform tasks and/or movements while experiencing an external force (an opposing athlete's body weight). That external force could potentially amplify the asymmetry, causing an athlete to be classified as "high risk". Testing asymmetry using BS could potentially be a better way to pre-screen for "high risk" of injury in contact sport athletes.

The current literature includes research measuring asymmetry while performing a jump of some kind: SJ, CMJ, or depth jump; however, there was a lack of studies measuring asymmetry under stress of a BS. This study investigated the asymmetry found in the lower body force output as measured by the BS and quantified by ground reactive forces. This can then open many more avenues on researching methods to: decrease the asymmetry in lower body force output as measured in athletes, maximize total lower body force output in athletes by vector addition principles, decrease lower body injury risks in athletes, and possibly introduce new training protocols for correcting asymmetry.

Thus, the purpose of this study was to determine if there was a correlation between the asymmetry of lower body force output and positioning on the field due to repetitive sports movements by measuring force output while performing a barbell back squat (BS) in NCAA Division II collegiate soccer, volleyball, softball, and baseball players. The goal of this study was to investigate if there was a correlation between asymmetric lower body force output and positioning on the field because of repetitive sports movements by measuring lower body force output while performing the BS. Specifically, this study investigated: 1) If position played on the field can predict asymmetry in athletes; 2) If athletes that play a specific position (right, center or left) have a different SA than athletes that play other positions; 3) If there is a difference in SA between sports represented; 4) If there was a difference in SA between males and females; and 5) If there was a relationship between SA in athletes and the position on the field played (left, center, or right).

Chapter 3: Methodology

Introduction

Understanding why athletes have asymmetrical force output was very important for both SC coaches and athletes alike. If the mechanism that was causing asymmetry, especially if the asymmetry was greater than 15%, can be counteracted by unilateral exercises or other interventions, the number of athletes categorized as "high risk" for injury may be reduced (Bell, et al., 2014; Hewit, et al., 2012; Impellizzeri, et al., 2007). Therefore, in this study understanding what causes asymmetry in athletes was the first step for strength coaches and athletes in becoming stronger and having a lesser chance of becoming injured because of repetitive sports movement based on the side of the field played on.

Approach to the research

This specific population: soccer, volleyball, baseball and softball players, were investigated because of the nature of the sport. Soccer, volleyball, baseball and softball all have a left, central, or right denotation to the positions of their respective games. For example, in soccer, a left defender primarily played on the left-side of the pitch. The positions of these sports for the most part, lack the freedom to play on other sections of their field (i.e. left position playing on the right-side of the field). There are specific situations where a right-side hitter may end up on the left-side of the field, but those situations are rare when compared to the traditional situations that occur. As mentioned earlier, repetitive sports movements can contribute to the occurrence of imbalances (Luk et al., 2013). In sports that require an athlete to stay on a specific side of the field, an athlete tends to perform a sport-specific movement on one side of his or her body more than the other side. This study investigated if the tendency to perform a sports-specific movement on one side versus the other, was the main factor causing athletes to be asymmetric in their force output, which then may predict risk of injury in athletes.

Positions

During data collection athletes self-reported the position they play and how long they've played their position. Depending on position reported, positions would be classified as left, center, or right. Positions that were considered on the left portion of the field were as follows: outside hitter, third base, left field, left outside back, left midfielder, and left forward. Positions that were considered a central position were as follows: goal keeper, center defender, center midfield, center forward, catcher, pitcher, shortstop, second base, center field, middle hitter, defensive specialist, or libero. Positions that were considered right-sided positions were: right outside back, right midfielder, right forward, first base, right field, setter and right-side hitter.

Groups

Before analysis, participants were grouped together in various ways. Participants were grouped by: individual sports teams (MS, WS, VB, SB, and BB), upper body (UB) sports (SB, BB, and VB), lower body (LB) sports (MS, WS), left-side positioned athletes, centrally positioned athletes, and right-side positioned athletes, INT (centrally positioned players), EXT (right and left positioned players), and males and females.

Setting

This study took place in the Strength and Conditioning lab and the Human Performance lab, both located in south central Colorado at approximately 7,500 ft.

Population

This study included a minimum of ten participants per team: soccer, volleyball, baseball, and softball from a NCAA Division II university located at approximately 7,500 ft. above sea level in south central Colorado. The primary investigator approached the head coach of each team to ask permission to request volunteers from these teams, during the off-season of these teams (see Appendix A).

Instrumentation

This study used the following instrumentation:

Computer: Two ASUS Intel Core i5 2-1 laptops (the primary investigator's, and one belonging to the university department were used in data collection. All data was analyzed using Microsoft Excel version 1702 (Microsoft home and student 2016), and SPSS version 24 (2016).

Data Score Card: A data score card (see Appendix B) that the primary investigator created was used to initially record the data prior to being transferred into Microsoft Excel version 1702 (Microsoft home and student 2016).

Force Plate: Two force plates (PASCO PS-2142 2-axis FORCE PLATE) gave two independent force readings (one for the right limb and one for the left limb) that were written down on the data score card in real time (see appendix B), before having the data transferred to a computer Excel spread sheet. All data was collected with a PASCO Scientific's "Capstone" data collection software, and was analyzed using SPSS.

Pasco software: A computer program used for analytical data collection.

Personal Footwear: Each participant used their own athletic footwear to BS in during the study.

Squat Rack: A standard Rogue squat rack located in the Strength and Conditioning lab was used for racking the bar bell when the participant was not performing the BS.

Weights: A standard Rogue weight set was used.

Research design/ Procedures

Before any research was performed, this study received approval from the university's Institutional Review Board (IRB) (see Appendix C). To recruit participants for this study, the researcher sent an email to the head coaches of men's and women's soccer, volleyball, softball, and baseball introducing himself and explaining the study, and explaining what was required by each volunteer to participate in this study (see Appendix A). Once the head coach agreed to allow the primary investigator to speak to his/ her team, the primary investigator then approached that team and briefed the athletes on the study. For those athletes who volunteered to participate in this study, the primary investigator had the participants sign the IRB consent form which then allowed the primary investigator to collect their personal contact information, and set up a time to perform the study (see Appendix D).

On the date and time of the previously set up appointment, the participants (one at a time) arrived at the Human Performance lab. Each participant then filled out a data score card including name, age, gender, sport, primary position, how long they have played said position (minimum one year required for inclusion), years of experience weight lifting (minimum of one year required for inclusion), and last known BS 1RM within the last calendar year (Appendix B). The 1RM was be checked against the records of the head SC coach at the university, since all athletes that attend the university have a BS 1RM recorded by a SC coach each year at the beginning of each sport's off-season. In the situation of an athlete not having a BS 1RM (i.e. a mid-year transfer or an athlete that was missing the day 1RMs were recorded), that athlete did not proceed any further in the research.

After completion of the data form, the participants had their basic anthropometric data taken, which included height (cm) and weight (kg). Height and weight were measured by the same SECA brand scale and stadiometer for all participants; all measurements were taken by the primary investigator while the participant was wearing their own athletic clothing that the participant performed a BS in minus his/ her shoes.

Following the measurements, the participant then began a standard 5-minute warm-up on a stationary bike (Monark Ergomedic 828 E), located in the Human Performance lab, similar to the research of Gullet et al. (2009) and Hooper et al. (2014). The participant then moved to the Strength and Conditioning lab located down the hall from the Human Performance lab. The participant then performed one warm-up set of eight reps at 50% of their 1RM of the BS (Lawrence & Carlson, 2015). Before the participant performed the warm-up set, the primary investigator informed the participant on proper BS technique and briefed him or her on the BS protocol, allowing a few reps to practice reaching appropriate depth for a successful BS. The primary investigator first demonstrated proper BS technique. During the warm-up and test itself, if a knee angle, measured by a goniometer, of 90-degrees was not met, the rep would not count. The participant performed up to three unsuccessful reps, before a failed test. A maximum of six reps were done to prevent reaching an extreme conditioning protocol. If the participant had not completed three successful reps by the 6th rep, the test was over and that participant's data was not included in the analysis. This was not likely to happen due to the fact that the BS was a foundational exercise for all sports to improve lower body strength and power (Braidot et al., 2007; Brandon et al., 2015; Čović, 2015; Gullett et al., 2009; Hagen et al., 1995; Hooper et al., 2014; Jakovljević et al., 2015; Lawrence & Carlson, 2015; Newton et al., 2006; Sato & Heise, 2012; Schwanbeck et al., 2009; Webster et al., 2015). Also, all athletes at the university perform the BS as a part of their strength and conditioning program.

After the warm-up, a three-minute break was given to ensure full recovery, and after calibration of the force plates, the primary investigator started the data collection by asking if the participant was ready to begin. After an audible confirmation, the participant was asked to step on to the two force plates and perform one rep of the participant's BS at 70% of his or her 1RM. The participant stepped on to the two force plates, then lifted the barbell off the Rogue squat rack that had been loaded with the correct amount of weight by the primary investigator with 70% of the participant's 1RM. It was noted that, if the value of 70% of the participant's 1RM did not land on an increment of five pounds then the closest increment of five pound below the actual 70% was used. This was for the safety of the participant, and did not skew the results of this study (Adams et al., 1992; Sato & Heise, 2012).

The participant performed a proper BS (see BS protocol below), then racked the weight on the Rogue fitness rack and stepped off the two force plates; the subject rested a minimum of one minute before performing that task again. In between each trial the force plates were zeroed. The participant performed a 70% 1RM squat a total of three successful times. The two force plates collected the amount of force exerted by each lower limb during both the eccentric and concentric phases of the BS movement during each rep.

Once the participant had finished, the participant was briefed with an explanation of the initial raw data, and its meaning and significance was explained. After the brief explanation, the participant had completed the test and was free to leave. The total time commitment for participating in the study was approximately 20- 30 minutes. Each participant was tested individually.

Back squat protocol/ technique

The BS protocol was as followed:

The primary investigator explained, demonstrated and walked the participant through how to un-rack the barbell during the participant's warm-up set of BS (see section below). Once ready, the participant entered the Rogue squat rack, stepped on to the two force plates, and un-racked the weight. Prior to performing the BS, the participant waited for an audible signal by the primary investigator. Once the primary investigator gave the go-ahead, the participant then performed the BS.

The BS motion begins with the knees and the hips fully extended. The hips and feet should be in a straight line, and both feet should be parallel and even to each other, not staggered. Next, the participant descended the weight in a controlled manner at a velocity that was comfortable for the participant until a 90-degree angle was reached at the knee joint. Then the participant drove the weight in the upward direction until the participant reaches full extension in the hip and knees. Then the participant paused briefly, allowing the primary investigator to stop the force plate software, before re-racking the barbell (see section below). The primary investigator confirmed the 90-degree knee angle by measuring with a goniometer during the warm-up reps. The primary investigator assessed the 90-degree knee angle with a goniometer, then found the height from the floor to the gluteus maximus where that 90-degree knee angle was met. The primary investigator then set the safety catches on the Rogue squat rack to that height and placed an elastic band across the safety catches to give the participant a physical cue when they have reached a proper BS depth. The participant only touched the elastic band and did not squat any deeper since the elastic nature of the band could possibly help the participant ascend the weight vertically and skew the reading by the force plates.

During the BS movement, the participant tried to keep their trunk upright during the whole movement. It was important to note that there was some forward lean at the bottom position of the BS. Since the primary investigator did not measure forward lean in the trunk, forward lean did not exclude a participant from the study if a knee angle of 90 degrees was measured by the goniometer.

Un-racking/ Re-racking the barbell

To begin, the participant straddled the force plates (one foot in front and one foot behind the force plate) and placed both hands on the barbell evenly spaced from the center of the barbell. Barbells have a knurl with a ring or Olympic lifting mark (with no knurl) in the center of the knurl on the areas that hands are most commonly placed (Kiesling, 2017). The knurl was for additional grip and the ring was to help the participant to visually measure equal hand placement from the center of the bar (Kiesling, 2017). Then the participant positioned themselves under the barbell aligning the barbell so it sits on the upper shoulder and trapezius area of the back. Note, if the participant has longer hair it may be more comfortable to move hair out of the way of the barbell so the barbell does not pinch or catch the hair. Once positioned under the bar the participant then brought both feet forward in front of both force plates, using their legs to lift the bar off the Rogue squat rack then carefully stepping back on to the force plates (there was a height difference of about two inches). The primary investigator or CPR/AED certified assistant was spotting the participant. Once the BS was complete, the participant stepped and leaned forward to re-rack the barbell.

Reliability

Based on the fact that this research has participants performing a weighted exercise, there should be a high level of reliability. Other researchers are able to duplicate the study if they have the means or access to a standard fitness squat rack, two force plates and a computer that has software capable of analyzing data. Force plates are considered the gold standard for collecting force (N); new methods of collecting force are compared against force plates to measure their reliability during weighted exercises such as the BS (Bell et al., 2014; Cormie et al., 2009; Driss et al., 2001; Hewit et al., 2012; Hodges et al., 2011; Impellizzeri et al., 2007; Luk et al., 2013; Markovic, Dizdar, Jukic, & Cardinale, 2004; Menzel et al., 2013; Newton et al., 2006; Simon & Ferris, 2008; Su, Song, Guo, & Yen, 2015; Webster et al., 2015; Witmer et al., 2010). For force plate comparison the intraclass correlation coefficient ranges between 0.924 - 0.975 for mean peak force, 0.977 - .0982 for peak force, and .721 - 0.964 for time to peak force (Markovic et al., 2004). The PASCO capstone version 1.2.0 (2014) software was reliable in reading the values from the force plate since it was the software that was specifically made to read the force plate data. SA was a reliable means in measuring asymmetry, because it plots the two values (the peak force output of each lower limb) against each other, and uses a trigonometry property to measure asymmetry; SA does not need a reference side to be set to understand what side the participant was asymmetric (Bishop et al., 2016; Zifchock et al., 2008). When using a SA, a positive value always represents asymmetry to the right, and a negative value always represent an asymmetry to the left (Bishop et al., 2016; Zifchock et al., 2008). This means that when using the SA, the primary investigator does not have to explicitly state that a positive value means that the asymmetry was to the D or ND side for each participant (or to the left or right-side) (Bishop et al., 2016; Zifchock et al., 2008). Since D or ND can change from participant to participant, it can easily be misinterpreted which side was asymmetric. The primary investigator was reliable because the primary investigator was the only one collecting data, and was checking technique using the same goniometer and ensuring the participants reach the 90-degree knee flexion; and the primary investigator was the only one directing each participant. Also, the primary investigator has been trained in testing the BS, and has completed two case studies to perfect the procedures and protocol.

Validity

The data collected from the research study should be valid based on the type of participants (i.e. athletes that have a side of the field denoted), the BS exercise (a bilateral strength and power movement that can be measured both bilaterally and unilaterally), and the testing protocol (similar to the peer reviewed and published research of Gullett et al., 2009). The testing protocol had each participant perform a BS while each leg was on an individual force plate that read independently of the other force plate. In this study, athletes that play a position located and labeled right, left, or center of the field, typically stay on that side of the field. The BS exercise was valid way to measure symmetry since it was a similar movement to the CMJ which was compared to validate other ways to measure symmetry (Impellizzeri et al., 2007; Robbins, 2011). The BS was a valid bilateral exercise to measure strength since multiple research studies have reported significant strength improvements after BS interventions (Braidot et al., 2007; Brandon et al., 2015; Čović, 2015; Gullett et al., 2009; Hagen et al., 1995; Hooper et al., 2014; Jakovljević et al., 2015; Lawrence & Carlson, 2015; Newton et al., 2006; Sato & Heise, 2012; Schwanbeck et al., 2009; Webster et al., 2015). Force plates are a valid way of measuring external force; force plates are generally what other methods of measuring force outputs are compared to, and are considered to be the gold standard (Cormie et al., 2009; Driss et al., 2001; Hewit et al., 2012; Hodges et al., 2011; Hooper et al., 2014; Impellizzeri et al., 2007; Luk et al., 2013; Markovic et al. 2004; Menzel et al., 2013; Newton et al., 2006; Su et al., 2015; Webster et al., 2015; Witmer et al., 2010). The PASCO capstone version 1.2.0 (2014) was a valid tool in reading the force plates since it was the software made specifically to read the force plates. The SA was a way of measuring symmetry angle that eliminates the need to choose a reference value, but was also highly correlated to the widely accepted symmetry index (Bishop et al., 2016; Zifchock et al., 2008).

Treatment of data/Statistical analysis

The data was initially recorded on the data score card (see appendix B), then it was transferred by the researcher into a Microsoft Excel spread sheet for convenience and consolidation, and then transferred again into SPSS for analysis. The independent variables in this study were position on the field or court (left, center, or right), self-reported by the participant, and sport, and gender. The dependent variable in this study was the SA, that was calculated from force plate values using the equation on page 62 (Bishop et al., 2016; Zifchock et al., 2008). To investigate if there was a relationship between SA and position played on the field, a Pearson's correlation analysis was run on SPSS. To investigate whether there was a difference in SA between male and female participants, between different sports, and between positions on the field, a multifactorial ANOVA was run on SPSS. If the ANOVA showed that there was a significant difference, then a post-hoc test was run to identify where the difference(s) were located. Lastly, a regression analysis was run on SPSS to see if SA can be predicted by position on the field, gender, and/or sport. All data was reported as group means ± standard deviations. No individual data was identified or reported. Statistical significance was set at $p < 0.05$. If there was reported statistical significance, then effect size was also calculated.

The identities of the participants were kept anonymous and confidential to protect the privacy of each participant. All of the raw data was digitized, and then the hard copies were destroyed. The digital copies were kept in a secure folder that was password protected and also backed up on an online server that was also password protected for a minimum of three calendar years, which only the primary investigator had access to.

Chapter 4: Results

A total of 55 student athletes volunteered to participate in this study. Of the 55, a total of 53 student athletes completed the study. The participants were made up of athletes from baseball (BB), men's soccer (MS), softball (SB), women's soccer (WS) and women's volleyball (VB) (N = 10 BB, N = 11 MS, N = 13 SB, N =11 WS, N = 10 VB) (Figure 17).

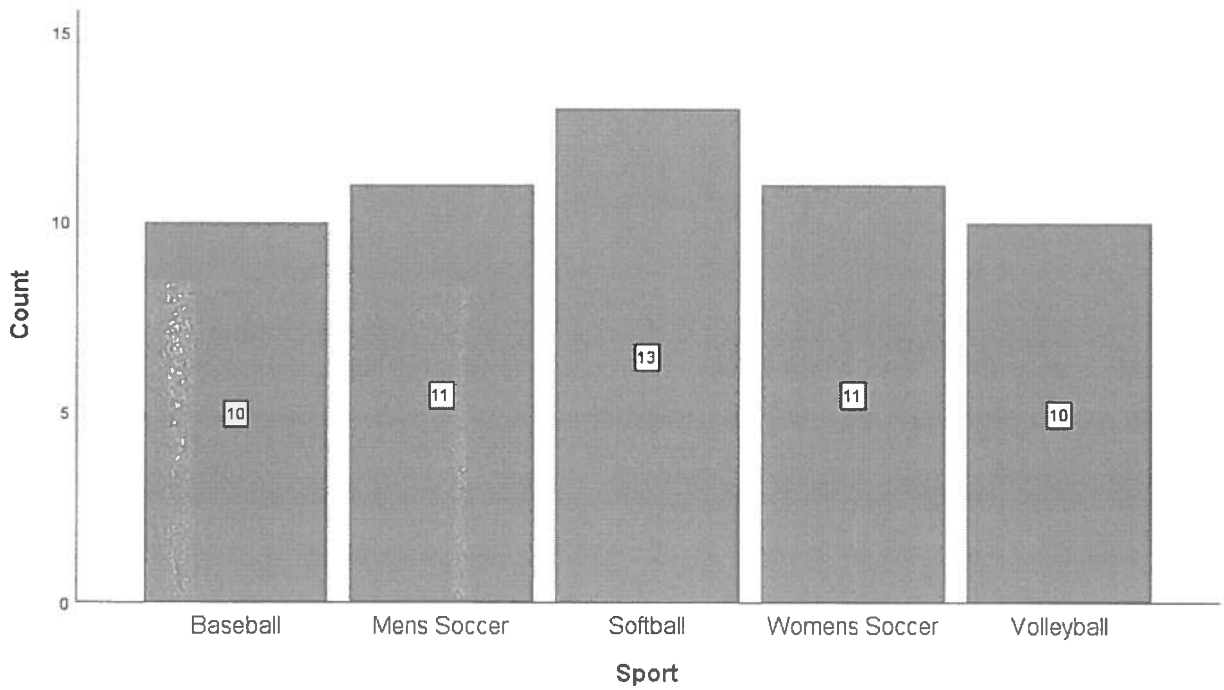

Figure 17. Participants per Sport

All data was analyzed using SPSS (Version 24, 2016) statistical analysis software. Statistical evaluation of the data was accomplished by using independent sample t-test's, ANOVAs and linear regressions. The independent t-tests were used to analyze the difference in means between two different groups (i.e., gender, upper body (UB) vs. lower body (LB) sports, and interior (INT) vs. exterior (EXT) positions). INT position are all positions located centrally or in the center third of the field or court. EXT positions are all positions that are not centrally located or in the center third of the field; in other words, the positions that are on the right or left-sides of the field or court. Statistical differences were considered significant at $p < 0.05$. For tests that are comparing means between more than two groups an independent t-test is not the appropriate test to run. ANOVAs were used to analyze the means between groups of three or more (i.e., different sports, and positions on the field/court: LCR). A linear regression was used to see if one could predict the outcome of the analysis depending on what the input variables were. In this study the input variables were the different groups (e.g. UB vs LB, INT vs EXT, and the different sports).

The independent variables of this study were the participants. The participants were divided into groups before any analysis was done depending on participant identifiers. Groups were compared based on position played on the field/court (LCR or INT and EXT), gender (male or female), or sport played (MS, WS, VB, SB, BB). The dependent variable in this study was the measured SA (degrees), measured during a BS, where a positive value denoted a SA to the right-side of the body and a negative value was noted a SA to the left-side of the body. This means a positive value denotes that the participant was asymmetric to the right, and a negative value denotes the participant was asymmetric to the left.

Subject Characteristics

This study had a total of 53 participants that were split into a variety of different groups: Table 1 below shows minimum, maximum, means and standard deviations of various descriptive characteristics of all of the participants together. Participants (N = 53) of this study had a mean age of 20.19 ± 1.26 yrs., height of 169 ± 9.29 cm, weight of 70.53 ± 10.92 kg, experience playing position of 9.06 ± 4.48 yrs., experience lifting of 5.16 ± 2.46 yrs., trial 1 average SA of

-0.33 ± 3.83 percent, trial 2 average SA of -0.52 ± 2.97 percent, trial 3 average SA of -0.52 ± 3.57 percent, and average SA of -0.36 ± 2.90 percent.

Table 1. Descriptive statistics of participants populations (N = 53)

Data Analysis Descriptive				
	Minimum	**Maximum**	**Mean**	**Std. Dev.**
Age (years)	18	23	20.19	1.25
Height (cm)	148	194	169.58	9.29
Weight (kg)	50	93.5	70.53	10.92
Exp. playing position (years)	1	19	9.06	4.48
Exp. lifting (years)	1	11	5.16	2.46
SA Trial 1 (percent)	-8.07	11.11	-0.33	3.83
SA Trial 2 (percent)	-7.97	8.23	-0.26	2.97
SA Trial 3 (percent)	-9.89	9.55	-0.52	3.57
SA Average (percent)	-5.91	9.59	-0.36	2.90

Table 2 and Table 3 show the same descriptive data split up by gender. Male participants (N = 19) of this study had a mean: age of 21 ± 1 yrs., height of 174 ± 9.08 cm, weight of 73.74 ± 8.76 kg, experience playing position of 9 ± 5 yrs., experience lifting of 6 ± 3 yrs., trial 1 average SA of 1.18 ± 3.84 percent, trial 2 average SA of -1.13 ± 3.36 percent, trial 3 average SA of -0.93 ± 3.35 percent, and average SA of -1.08 ± 3.09 percent (see Table 2). Female participants (N = 34) of this study had a mean: age of 20 ± 1 yrs., height of 166 ± 8.17 cm, weight of 68.74 ± 11.70 kg, experience playing position of 9 ± 4 yrs., experience lifting of 5 ± 2 yrs., trial 1 average SA of -1.17 ± 3.61 percent, trial 2 average SA of -1.04 ± 2.45 percent, trial 3 average SA of -1.33 ± 3.47 percent, and average SA of -1.17 ± 2.49 (see Table 3).

Table 2. Descriptive statistics of male participants (N = 19)

Data Analysis Descriptive Male				
	Minimum	**Maximum**	**Mean**	**Std. Dev.**
Age (years)	18	23	21	1
Height (cm)	165	194	174	9.08
Weight (kg)	56	90.50	73.74	8.76
Exp. playing position (years)	2	19	9	5
Exp. lifting (years)	2	11	6	3
SA Trial 1 (percent)	-4.69	11.11	1.18	3.84
SA Trial 2 (percent)	-3.89	8.23	1.13	3.36
SA Trial 3 (percent)	-2.70	9.55	.93	3.35
SA Average (percent)	-1.96	9.59	1.08	3.09

Table 3. Descriptive statistics of female participants (N = 34)

Data Analysis Descriptive Female				
	Minimum	**Maximum**	**Mean**	**Std. Dev.**
Age (years)	18	22	20	1
Height (cm)	148	190	166.68	8.17
Weight (kg)	50	93.50	68.74	11.70
Exp. playing position (years)	1	18	9	4
Exp. lifting (years)	1	10	5	2
SA Trial 1 (percent)	-8.07	6.63	-1.17	3.61
SA Trial 2 (percent)	-7.97	3.55	-1.04	2.45
SA Trial 3 (percent)	-9.89	3.81	-1.33	3.47
SA Average (percent)	-5.91	3.27	-1.17	2.49

Figure 18 shows the breakdown of the positions played on the field (left, center or right). In this study there were 14 participants that played on the left side of the field or court, 28 participants that played in the center of the field or court, and 11 participants that played on the right side of the field or court.

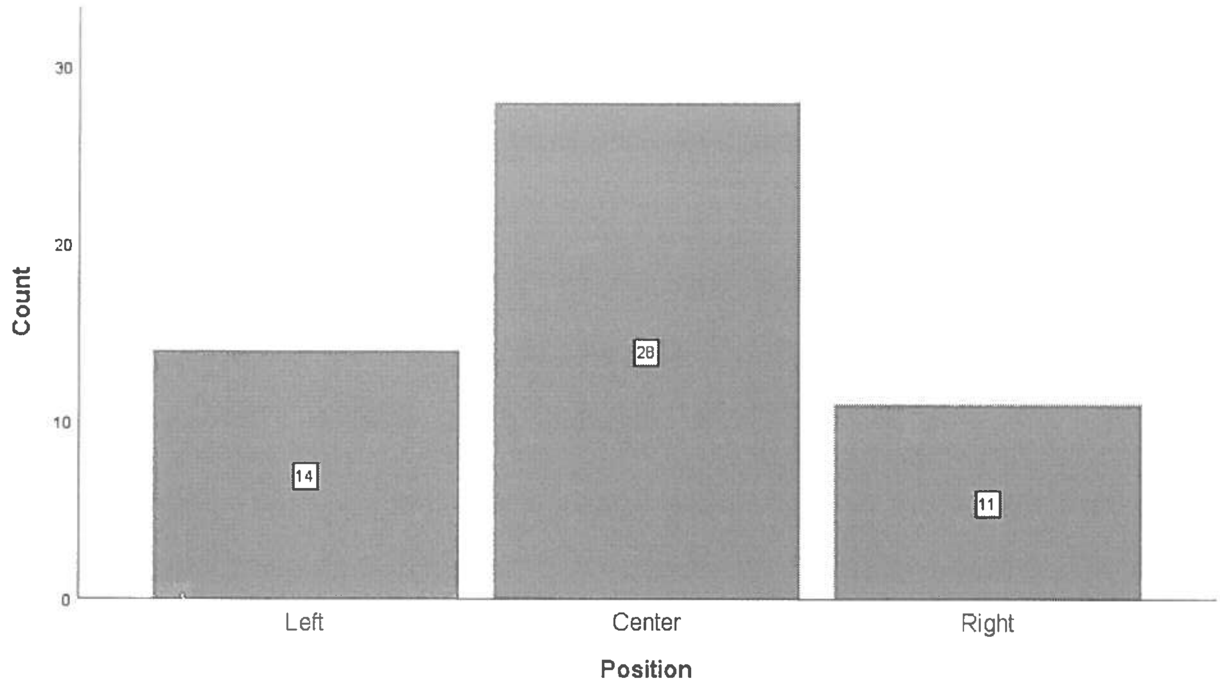

Figure 18. Participants by position

Figure 19 shows the breakdown of positions played on the field (left, center or right) by sports teams. In this study there were eight participants from baseball (one left-side, five center, and two right-side), 11 participants from men's soccer (four left-side, three center, and four right-side), 13 participants from softball (five left-side and eight center), 11 participants from women's soccer (two left-side, seven center, and two right-side), and ten participants from volleyball (two left-side, five center, and three right-side).

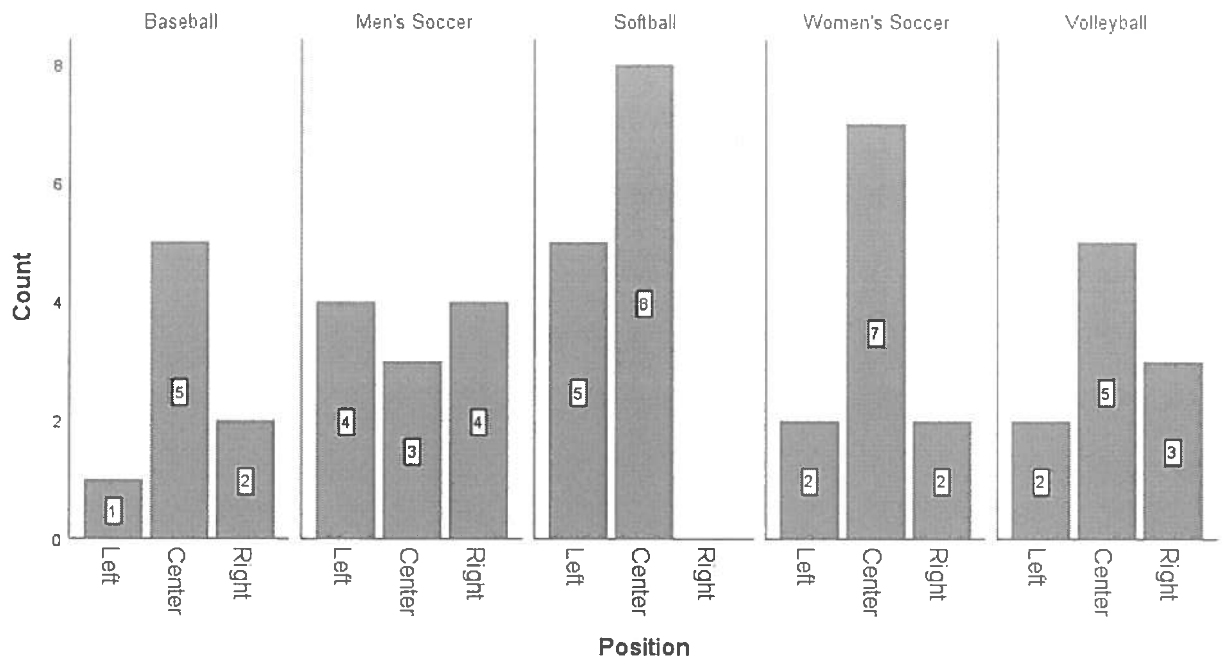

Figure 19. Position break down (LCR) by sport.

Team Characteristics

The participants of this study (N = 53) had a mean age: 20.19 ± 1.25 years, height: 169.58 ± 9.28 cm, weight: 70.53 ± 10.91 kg, time played in position: 9.06 ± 4.48 years, and experience lifting weight: 5.16 ± 2.46 years (see Table 1 and Table 4). The BB group (N = 8) consisted of participants that had a mean age, height, weight, and average SA of 21 ± 1 years, 176.75 ± 9.41 cm, 76.63 ± 7.41 kg, and -0.11 ± 1.38 percent respectively (see Table 4). The MS group (N = 11) consisted of participants that had a mean age, height, weight, and average SA of 22 ± 1 years, 173.36 ± 9.00 cm, 71.64 ± 9.36 kg, and 1.94 ± 3.73 percent respectively (see Table 4). The SB group (N = 13) consisted of participants that had a mean age of 19 ± 1 years, height of 163.23 ± 5.15 cm, weight of 67.23 ± 12.26 kg, and average SA of -1.55 ± 2.62 percent (see

Table 4). The WS group (N = 11) consisted of participants that had a mean age of 19 ± 1 years, height of 163.14 ± 5.51 cm, weight of 63.23 ± 8.89 kg, and average SA of -0.56 ± 2.49 percent (see Table 4). The VB group (N = 10) consisted of participants that had a mean age of 20 ± 1 years, height of 175.05 ± 8.07 cm, weight of 76.75 ± 10.08 kg, and average SA of -1.35 ± 1.38 percent (see Table 4, and Appendix E SPSS Outputs: Raw SA Data).

Table 4. Descriptive statistics by team

	LCR side participants (N)	Total Participation in Sport (N)	Experience lifting (yrs.)	Experience in Position (yrs.) ± SD	Back Squat 1RM ± SD	Height (cm) ± SD	Weight (kg) ± SD	Average SA (percent) ± SD
Baseball	1,5,2	8	7 ± 3	7 ± 3	282 ± 41	176.75 ± 9.41	76 ± 63	-0.11 ± 1.38
Men's Soccer	4,3,4	11	6 ± 2	11 ± 6	237 ± 49	173.36 ± 9.00	71.64 ± 9.39	1.94 ± 3.73
Softball	5,8,0	13	4 ± 2	10 ± 5	192 ± 26	163.23 ± 5.15	67.23 ± 12.26	-1.55 ± 2.62
Women's Soccer	2,7,2	11	5 ± 3	8 ± 4	193 ± 36	163.14 ± 5.51	63.23 ± 8.89	-0.56 ± 2.49
Volleyball	2,5,3	10	5 ± 2	9 ± 3	175 ± 31	175.05 ± 8.07	76.75 ± 10.08	1.35 ± 2.44
Total	**14,28,11**	**53**	**5 ± 2**	**9 ± 4**	**212 ± 51**	**169.58 ± 9.29**	**70.53 ± 10.92**	**-0.36 ± 2.90**

Group Characteristics

The left group consisted of participants that played a position located on the left-side of the field/ court in MS, WS, VB, SB, and BB. Positions that would be considered to be located on left-side of the field are: outside hitter, third base, left field, left outside back, left midfielder, and left forward. The left group (N = 14) consisted of participants that had a mean age of 20 ± 1 years, height of 166.82 ± 6.64 cm, weight of 67.54 ± 9.63 kg, and average SA of -0.32 ± 2.31 percent. The center group consisted of participants that played a position located in the center third of the field/court in MS, WS, VB, SB, BB. Positions that were considered central position are as followed: goal keeper, center defender, center midfield, center forward, catcher, pitcher, shortstop, second base, center field, middle hitter, defensive specialist, or libero. The center group (N =28) consisted of participants that had a mean age of 20 ± 1 years, height of 170.45 ± 11.47 cm, weight of 71.38 ± 11.94 kg, and average SA of -0.92 ± 2.58 percent. The right group consisted of participants that played a position located on the right-side of the field/court in MS, WS, VB, SB, and BB. Positions that would be considered right-sided positions were: right outside back, right midfielder, right forward, first base, right field, setter and right-side hitter. The right group (N =11) consisted of participants that had a mean age of 21 ± 1 years, height of 170.91 ± 4.46 cm, weight of 72.18 ± 9.86 kg, and average SA of 1.00 ± 4.00 percent (see Table 4, and Appendix E SPSS Outputs: Raw SA Data).

When comparing descriptive characteristics between left-, center and right-side groups the primary investigator noticed that there was very little difference ($p > 0.05$) in experience lifting (yrs.), BS 1RM (kg), and weight (kg) (left-side: 5 ± 2; 213 ± 48; 67.54 ± 9.63; center: 5 ± 3; 206 ± 50; 71.38 ± 11.94; right-side: 5 ± 2; 226 ± 60; 72.18 ± 9.86). However, the primary investigator noticed that there were noticeable differences ($p > 0.05$) between experience in position (yrs.), height (cm), average SA (percent) and total participation (N) (left-side: 9 ± 5; 166.82 ± 6.64; -.032 ± 2.31; center: 10 ± 4; 170.45 ± 11.47; -0.92 ± 2.58; right-side: 8 ± 4; 170.91 ± 4.64; 1.00 ± 4.00) (see Appendix E: SPSS Outputs).

The UB group consisted of the sports of BB, SB, and VB (

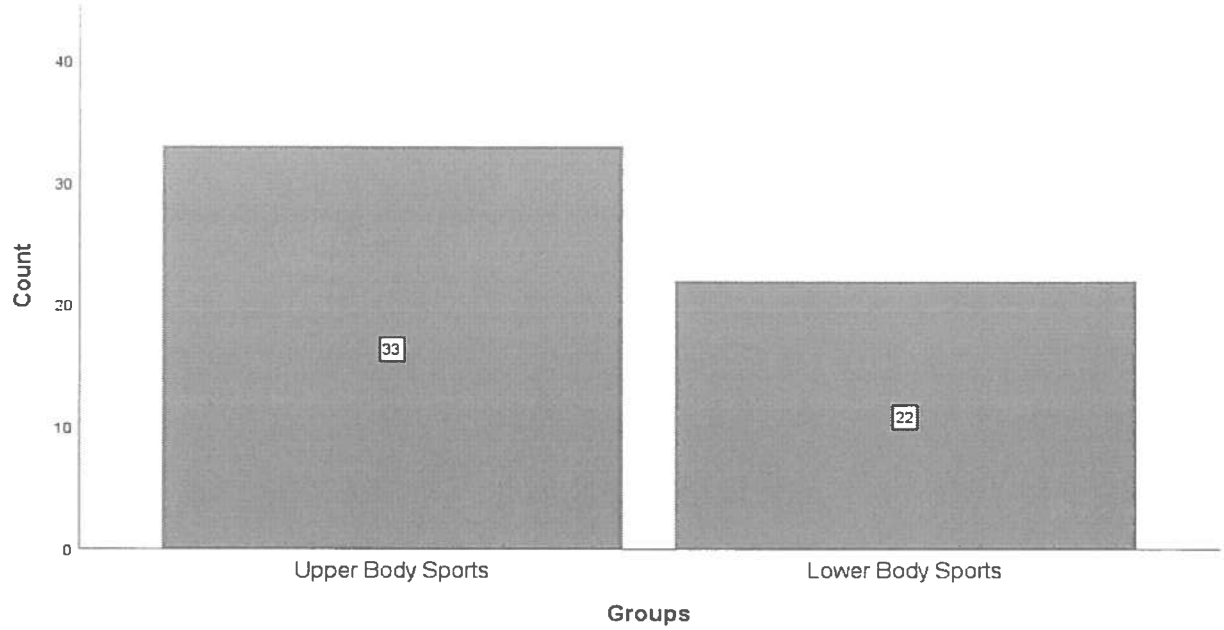

Figure ***20***). These sports were selected because their defining sports movements act in the upper body (e.g. hitting and throwing). The UB group (N = 31) consisted of participants that had a mean age of 20 ± 1 years, height of 170.53 ± 9.54 cm, weight of 72.73 ± 11.22 kg, and average SA of -1.12 ± 2.31 percent. The LB group consisted of the sports of MS and WS. These sports were selected because their defining sports movements act in the lower part of the body (e.g. kicking). The LB group (N = 22) consisted of participants that had a mean age of 20 ± 1 years, height of 168.25 ± 8.97 cm, weight 67.43 ± 9.91 kg, and average SA of 0.69 ± 3.35 percent (see Table 5 and Appendix E: SPSS Outputs).

When comparing descriptive characteristics between UB and LB groups there was very little difference ($p > 0.05$) in lifting experience (yrs.), experience in position (yrs.), BS 1RM (kg), height (cm); UB: 5 ± 2; 9 ± 4; 210 ± 54; 170.53 ± 9.54; 5 ± 3; 10 ± 4; LB: 5 ± 2; 9 ± 5; 215 ± 48; 168.25 ± 8.97. The primary investigator noticed that there were differences in weight (kg), average SA (percent), and total participation (N) (UB: 73.76 ± 11.22; -1.12 ± 2.31; 31; LB: 67.43 ± 9.91; 0.69 ± 3.35; 22; $p > 0.05$) (see Table 5).

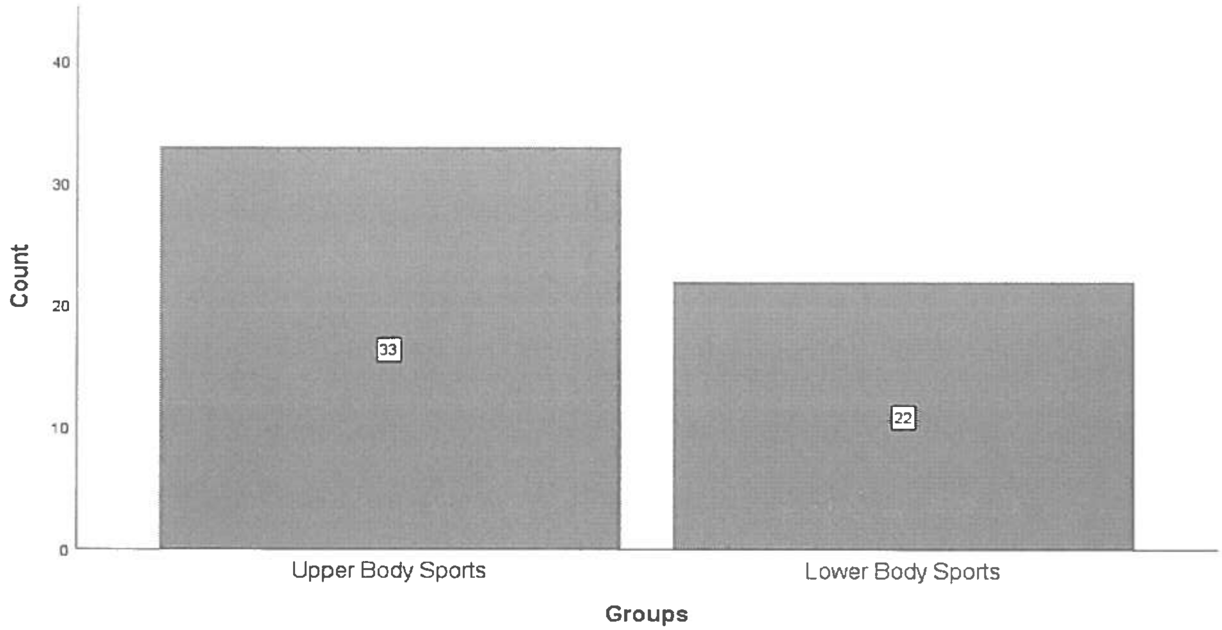

Figure 20. Participation between UB and LB groups

Table 5. Descriptive breakdown by group

	Experience lifting (yrs.) ± SD	Experience in Position (yrs.) ± SD	Back Squat 1RM (kg) ± SD	Height (cm) ± SD	Weight (kg) ± SD	Average SA (percent) ± SD	Total Participation in Sport (N) ± SD
Upper Body (UB) group	5 ± 2	9 ± 4	210 ± 54	170.53 ± 9.54	72.73 ± 11.22	-1.12 ± 2.31	31
Lower Body (LB) Group	5 ± 2	9 ± 5	215 ± 48	168.25 ± 8.97	67.43 ± 9.91	0.69 ± 3.35	22
Internal Group (INT)	5 ± 3	10 ± 4	206 ± 50	170.45 ± 11.47	69.58 ± 9.81	-0.92 ± 2.58	28
External (EXT) Group	5 ± 2	8 ± 5	219 ± 53	168.62 ± 6.09	70.53 ± 10.92	0.26 ± 3.16	25
Male group	6 ± 3	9 ± 5	256 ± 50	174.79 ± 9.08	73.74 ± 8.76	1.08 ± 3.09	19
Female Group	5 ± 2	9 ± 4	187 ± 31	166.68 ± 8.17	68.74 ± 11.70	-1.17 ± 2.90	34
Left-side Group	5 ± 2	9 ± 5	213 ± 48	166.82 ± 6.64	67.54 ± 9.63	-0.32 ± 2.31	11
Center group	5 ± 3	10 ± 4	206 ± 50	170.45 ± 11.47	71.38 ± 11.94	-0.92 ±2.58	28
Right-side group	5 ± 2	8 ± 4	226 ±60	170.91 ± 4.64	72.18 ± 9.86	1.00 ± 4.00	14

The INT group consisted of all participants that were positioned in the center third of the field/court in MS, WS, VB, SB, BB (see Table 6). Table 6 and Figure 21 give a breakdown of how many participants from each team were considered to be INT or EXT. Figure 19 shows a breakdown of how many players for each sports team played a position located on the left side, center, or right side of the field or court. Positions that were considered central position were as follows: goal keeper, center defender, center midfield, center forward, catcher, pitcher, shortstop, second base, center field, middle hitter, defensive specialist, or libero. The INT group (N = 28) consisted of participants that had a mean age, height, weight, and average SA of 22 ± 1 years, 170.45 ± 11.47 cm, 69.58 ± 9.81kg, and -0.92 ± 2.58 percent respectively (see Table 5). The EXT group consisted of all participants that were positioned not in the center third (left or right) of the field/court in MS, WS, VB, SB, BB. Positions that were considered to be located EXT group were: outside hitter, third base, left field left outside back, left midfielder, left forward, right outside back, right midfielder, right forward, first base, right field, setter and right-side hitter. The EXT Group (N =25) consisted of participants that had a mean age of 20 ± 1 years, height of 168.62 ± 6.09 cm, weight of 70.53 ± 10.52 kg, and average SA of 0.26 ± 3.16 percent (see Table 5, Table 6 and Appendix E: SPSS Outputs). When comparing descriptive characteristics between INT and EXT groups results were fairly consistent in experience lifting (yrs.), BS 1RM (kg), height (cm), weight (kg), and total number of participants (N): INT:5 ± 3; 206 ± 50; 170.45 ± 11.47; 69.58 ± 9.81; 28; EXT: 5 ± 2; 219 ± 53; 168.62 ± 6.09; 70.53 ± 10.92; 25. However, there was a noticeable difference ($p > 0.05$) in experience in position (yrs.), average SA (percent): INT 10 ± 4; -0.92 ± 2.58; EXT: 8 ± 5; 0.26 ± 3.16 (see Table 5).

Table 6. INT/EXT breakdown by team

	Exterior Participants (N)	Interior Participants (N)	**Total (N)**
Baseball	3	5	**8**
Men's Soccer	8	3	**11**
Softball	5	8	**13**
Women's Soccer	4	7	**11**
Volleyball	5	5	**10**
Total	**25**	**28**	**53**

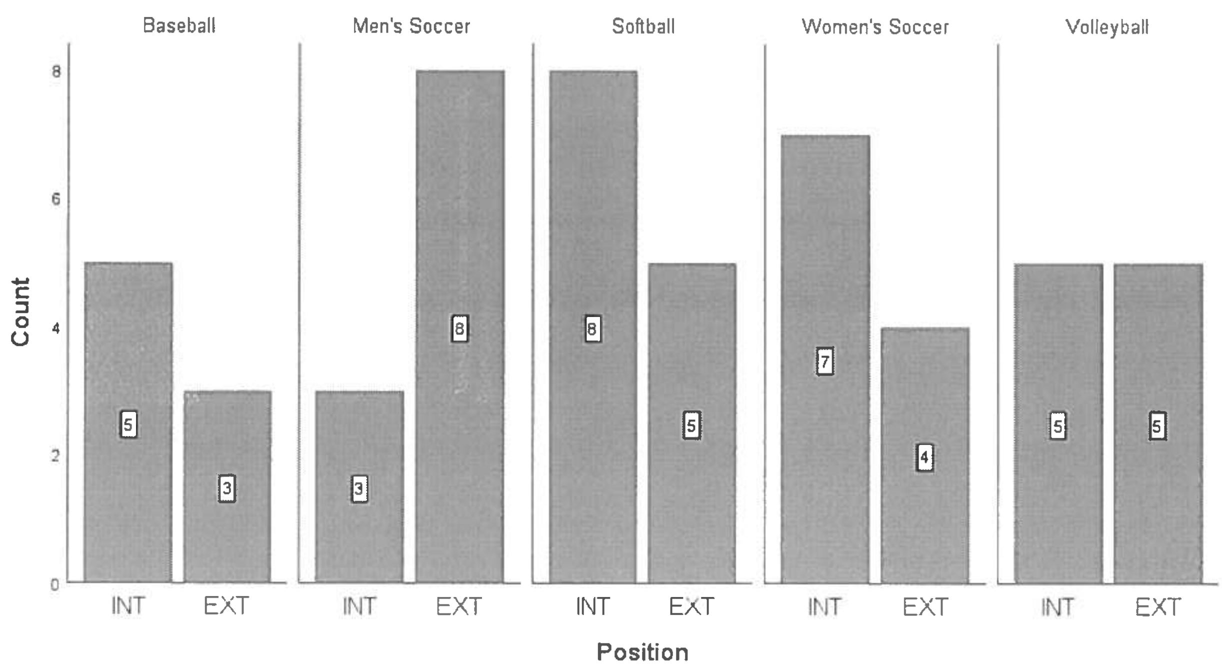

Figure 21. Participation between INT and EXT groups

The male group consisted of all male participants on each team. In this experiment the male group consisted of MS and BB. The male group (N = 19) consisted of participants that had a mean age, height, weight, and average SA of 21 ± 1 years, 174.79 ± 9.08 cm, 73.74 ± 8.76 kg, and 1.08 ± 3.09 percent (see Figure 22 and Table 5). The female group consisted of all female participants on each team. In this experiment the female group consisted of WS, VB, and SB. The female group (N = 34) consisted of participants that had a mean age, height, weight, and average SA of 20 ± 1 years, 166.68 ± 8.17 cm, 68.74 ± 11.70 kg, and -1.17 ± 11.70 percent (see Figure 22 and Table 5). When comparing descriptive characteristics between male and female groups results were fairly consistent in experience lifting (yrs.), and experience in position (yrs.) (male: 6 ± 3; 9 ± 5, female: 5 ± 2; 9 ± 4). However, there were noticeable difference ($p > 0.05$) in BS 1RM (kg), height (cm), weight (kg), average SA (percent), and total participation (N): male: 256 ± 50; 174.79 ± 9.08; 73.74 ± 8.76; 1.08 ± 3.09; 19; female: 187 ± 31; 166.68 ± 8.17; 68.74 ± 11.70; -1.17 ± 2.90; 34 (see Table 5).

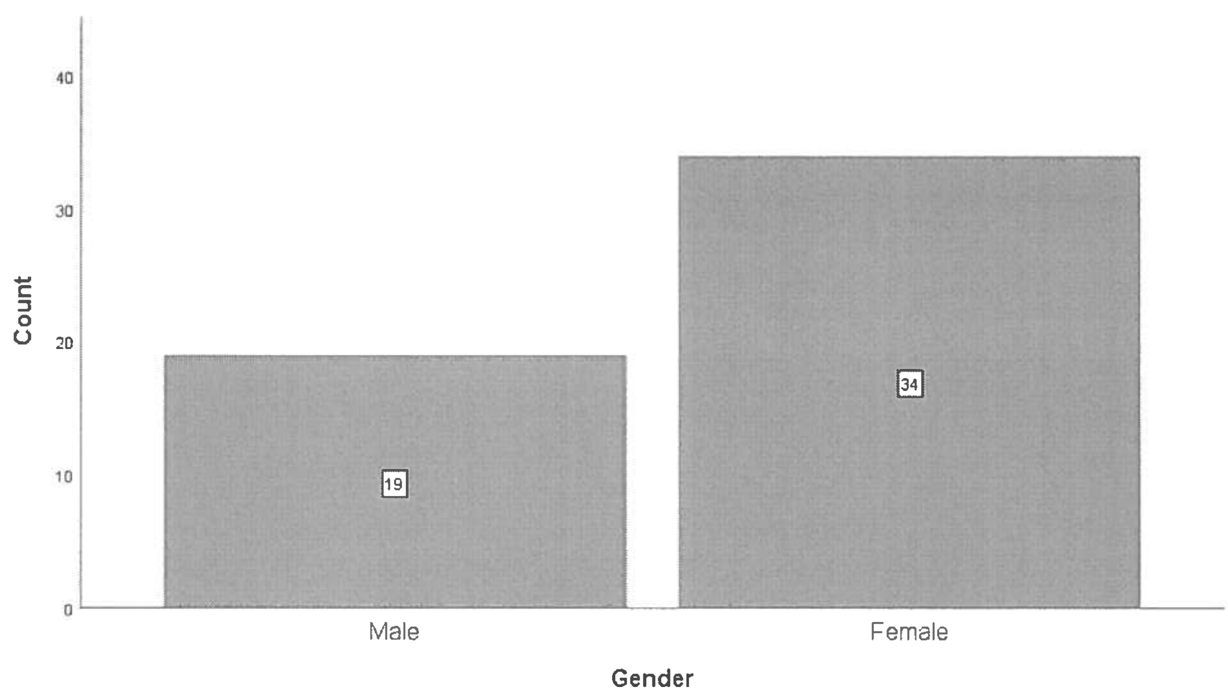

Figure 22. Participation by gender

Comparison by Paired Group

Research question three questioned if there was a difference in SA between gender (men and women). An independent t-test was run to investigate if there was a difference in average SA between gender (male and female). After analyzing the data, it was found that there was a significant difference in the average SA between males (M = 1.08 ± 3.09 percent) and females (M = -1.17 ± 2.90 percent). The difference, 2.25 percent, 95% CI [0.68, 3.81] was significant t(51) = 2.89 *p* = 0.01, with a medium effect size (r = 0.38).

Another independent t-test was run to investigate the possible difference in average SA between UB and LB groups. After analysis, the results showed statistical significance in average SA between UB (M = -1.12 ± 2.31 percent) and LB groups (M = 0.69 ± 3.35 percent. The difference, 1.81 percent, 95 CI [-3.37, -0.25] was significant t(51) = 2.33, *p* = 0.02, with a medium effect size (r = 0.31) (see Table 5 and Appendix E: Independent t-test).

The first research question asked if there was a difference between sports for SA. An ANOVA was run to determine if there was a difference in average SA between sports teams (N = 5). The results of the ANOVA showed there was a significant difference between sports teams, F (4, 52) = 2.99, *p* = 0.03, ω = 0.36. Note, the effect size of an ANOVA is denoted as ω. To reveal where the significance was, a Tukey HSD post-hoc test was run. The Tukey HSD post-hoc test revealed that there was a significant difference in average SA between MS and SB (*p* = 0.02). Although not significant, the Tukey post-hoc test revealed the difference in average SA between MS and VB was trending toward significance with a *p* value of 0.056. See Appendix E: SPSS Outputs: Post-hoc test for details.

Research question number four asked if athletes that play on a specific third (left, center, or right) of the field have a different asymmetry angle than players on another third of the field.

According to the research done in this study, athletes that play one specific third of the field (left, center, or right) do not have a different SA than athletes that play on a different third of the field, $F(2,52) = 1.78$, $p = 0.18$, $\omega = 0.17$.

Correlation

The second research question was, is there a relationship between positions played on the field and SA in athletes. A bivariate correlation was run on SPSS, between position on the field and average SA. The output of a bivariate correlation is the Pearson's r value. Pearson's r value denotes the significance of the correlation there was no statistically significant correlation found between the two variables ($r = 0.14$, $p = 0.33$). Additional bivariate correlations were run between men vs average SA, and women vs average SA. No statistically significant correlation was discovered between the singular gender groups ($r = 0.23$, $p = 0.35$ for men ($N = 19$) and, $r = -0.01$, $p = 0.99$ for women ($N = 34$) respectively) (see Table 7, Table 8, Table 9, and Appendix E: Correlation). Table 9 shows the correlation of average SA and position on the field in both men and women combined.

Table 7. Bivariate Correlation: Position on the field vs average SA for men

Correlations			
		Average Symmetry Angle	Third of the field played (men)
Average Symmetry Angle	Pearson Correlation	1	0.226
	Sig. (2-tailed)		0.352
	N	19	19
Third of the field played (men)	Pearson Correlation	0.226	1
	Sig. (2-tailed)	0.352	
	N	19	19

Table 8. Bivariate Correlation: Position on the field vs average SA for women

Correlations			
		Average Symmetry Angle	Third of the field played (women)
Average Symmetry Angle	Pearson Correlation	1	-0.002
	Sig. (2-tailed)		0.992
	N	34	34
Third of the field played (women)	Pearson Correlation	-0.002	1
	Sig. (2-tailed)	0.992	
	N	34	34

Table 9. Bivariate Correlation: Position on the field vs average SA for men and women

Correlations			
		Average Symmetry Angle	Third of the field played (Men & Women)
Average Symmetry Angle	Pearson Correlation	1	0.138
	Sig. (2-tailed)		0.325
	N	53	53
Third of the field played (Men & Women)	Pearson Correlation	0.138	1
	Sig. (2-tailed)	0.325	
	N	53	53

Regression Analysis

The final research question was: does position on the field, gender, or sport predict asymmetry in athletes? According to the regression analysis, there was statistical significance when using gender as a predictor for average SA for all subjects ($r = 0.38$, $r^2 = 0.14$, $F(1, 52) = 8.34$, $p = 0.01$). When using sport as a prediction variable, the regression analysis did not show statistical significance, but was trending toward statistical significance ($r = 0.25$, $r^2 = 0.06$, $F(1, 52) = 3.48$, $p = 0.07$). When using position as a prediction variable, the regression analysis also did not show statistical significance ($r = 0.14$, $r^2 = 0.02$, $F(1,52) = 0.99$, $p = 0.33$). Combining the two predictors of gender and sport, that regression analysis showed the highest statistical significance out of the three predictors (position on the field, gender, and sport) by themselves regression analyses ($r = 0.39$, $r^2 = 0.15$, $F(2, 52) = 4.54$, $p = 0.02$). However, when rearranging sport's order from lowest average SA to highest average SA, the regression analysis showed new values of $r = 0.42$, $r^2 = 0.18$, $F(1, 52) = 10.89$, $p = 0.00$ (see Figure 23, and Appendix E:

Regression Analysis). In conclusion, it does not make sense to run a regression analysis on nominal values. However, it does make sense to compare the mean SA for each sub-division, which in essence is research questions one, three, and four.

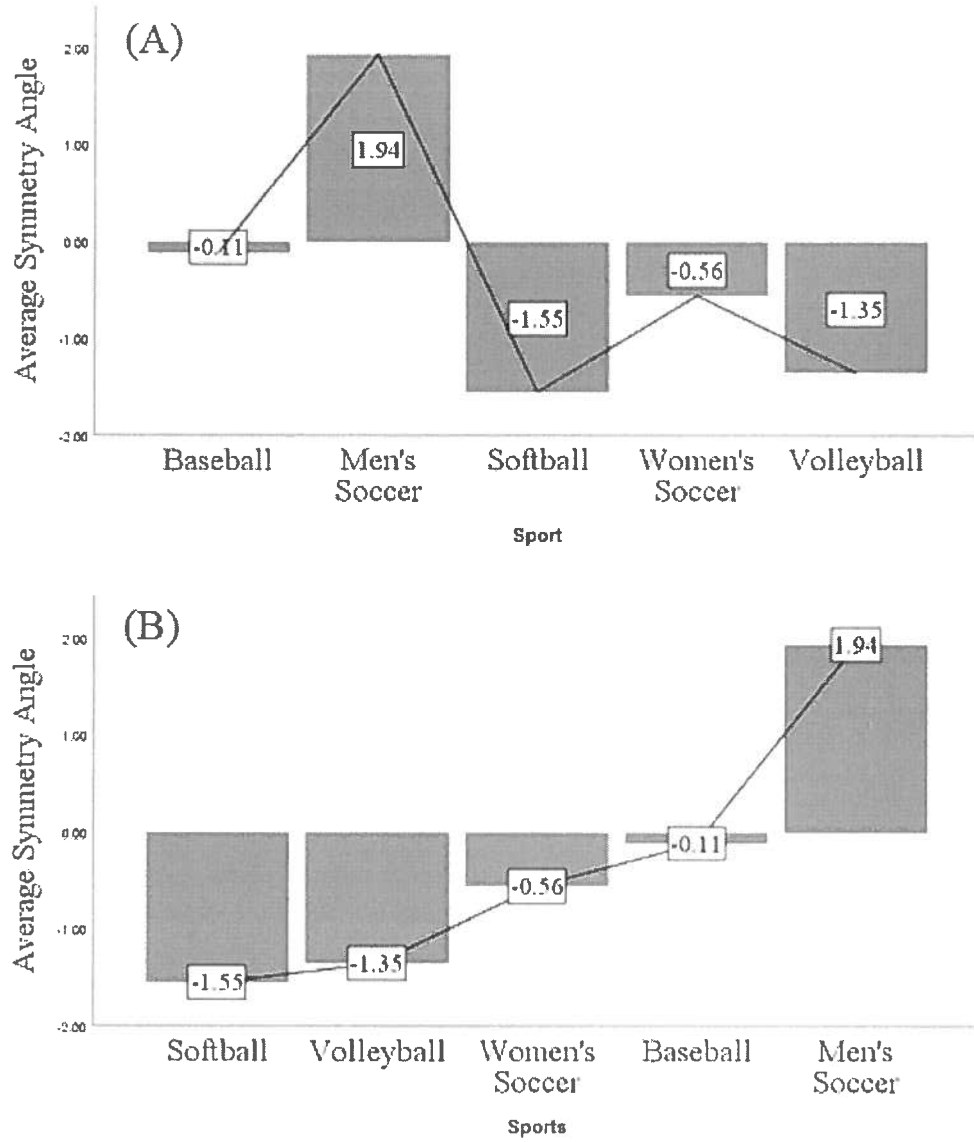

Figure 23. Average SA by sport arranged arbitrarily (A) vs Average SA by sport arranged from most negative to most positive (B)

Hypotheses

It was hypothesized that athletes that play on the right-side or the left-side of the field would have a larger symmetry angle than an athlete that plays in the center of the field. A planned contrast was run between exterior (left side and right-side combined) and interior (central) positioned athletes to compare average SA $t(50) = 1.60$, $p = 0.12$, $r = 0.03$ (see Table 5 and Appendix E: SPSS Outputs: ANOVA). No statistical significance was found between interior ($M = -0.92 \pm 2.58$ percent) and exterior ($M = 0.26 \pm 3.16$ percent) positions when comparing average SA. The results showed a difference between means of -1.18 percent, 95% CI [-2.765, 0.403], $t(50) = 1.60$, $p = 0.12$, $r = 0.03$. With no statistical significance, the primary investigator rejects the hypothesis of exterior positioned athletes having a larger (more positive or more negative) SA compared to centrally positioned athletes.

The primary investigator also hypothesized that there was a difference in SA between men's and women's soccer athletes (LB sports) and baseball, softball, and volleyball athletes (UB sports). An independent t-test was run between UB sports ($M = -1.12 \pm 2.31$ percent) and LB sports ($M = 0.69 \pm 3.35$ percent). The results showed that the difference between means (-1.81 percent, 95% CI [-3.37, -0.25]) was a statistically significant difference with a medium effect size ($r = 0.31$, $t(51) = -2.32$, $p = 0.02$, $d = 0.78$). Therefore, the primary investigator accepts the hypothesis that there was a difference in SA between UB sports and LB sports.

Chapter 5: Discussion

The purpose of this study was to determine if there was a correlation between lower body force output asymmetry and positioning on the field in NCAA Division II collegiate athletes. This study determined a correlation by measuring force output while performing a BS and calculating SA. The BS was performed at 70% of the participant's 1RM while standing on two force plates that measured the normal force (N) exerted while performing the BS. Athletes from men's and women's soccer, volleyball, softball, and baseball volunteered to participate in this study. All participation was done outside of the competition season so that the fatigue of competition would not skew the results of the study, and more importantly that this study did not take away or distract the participants from their collegiate seasons. The original hypotheses were: 1) an athlete that plays on the right-side or the left-side of the field or court (EXT) would have a larger SA than an athlete that plays in the center of the field or court (INT); 2) The SA of UB sports (baseball, softball, and volleyball) and LB (men's and women's soccer) would be different.

Compared between groups there was no difference between lifting experience and experience playing the position. There was also no difference between groups when measuring BS 1RM max with the exception of the comparison between males (256 ± 50 lbs.) and females (187 ± 31 lbs.) (see Table 5).

Research Questions and Hypotheses

During the analysis process, the primary investigator questioned if there was a difference in SA between players on the EXT (left and right sides) compared to players playing centrally (INT). This means does playing on the outside or externally on the field or court cause a player to have a difference in SA (favor one side) more than a player that played centrally? In Table 5, when comparing INT (central positions) and EXT (left and right positions) the largest negative value (asymmetric to the left) was from the INT group not the EXT group. This finding contradicts what the primary investigator hypothesized. Data analysis showed no statistically significant difference between SA in INT and EXT players ($p = 0.14$). Therefore, the first hypothesis: An athlete that plays on the right side or the left side of the field or court (EXT) would have a larger SA than an athlete that plays in the center of the field or court (INT), is not accepted, therefore the null hypothesis is accepted and the primary investigator rejects the alternate hypothesis.

The primary investigator suspected that values of the right-side participants were canceling out the values of the left-side participants. For example, if the participants that were positioned on the left-side (part of the EXT group) had a SA value of -1.00, and the participants that were positioned on the right-side (part of the EXT group) of the field had a SA value of 1.00 then the EXT group would have a collective SA value of 0.00. If the INT group had a value at all then that group would always have a SA value greater than the EXT group. To address that possibility, an additional comparison of average SA was run. This time the absolute value of the average SA of each participant was analyzed. The results of the ANOVA showed even less significance ($p = 0.68$) when compared to the original comparison of means analysis. This leads to the conclusion that positioning on the field did not have a significant effect on the average SA (see Appendix E). In this experiment, four out of the five teams had at least one participant that played in each of the three positions. The one sport that did not have at least one participant that played in each position was softball (see Figure 19).

The five research questions were ordered in level of significance to the study. One of the main questions (research question two) of this study and the centerpiece of the research design was the question: Was there a relationship between position played on the field and SA in athletes? A bivariate correlation was run to compare all participants that play on a specific third of the field. For example, the average SA of men that played on the right-side of the field or court will be compared to women who played on that same side of the court or field. The bivariate analysis showed a small correlation, and a small effect size, but it was not statistically significant between the two variables ($p = 0.33$, $r = 0.14$). The primary investigator ran two additional bivariate correlations: analysis between men's average SA versus position and women's average SA versus position, to see if there was a correlation between average SA and position in only males or only females. The results showed no statistical significance between the singular gender groups (male: $p = 0.35$, $r = 0.23$, and female: $p = 0.99$, $r = -0.01$ respectively). This means the values that were found in average SA do not correlate with position on the field, and do not affect men and women differently. This result's agrees with the previously discussed research that stated that PAP interventions, bilateral strength asymmetry and BS technique did not affect men and women differently (Bailey, Sato, Burnett, & Stone, 2015; Hooper et al., 2014; Witmer et al., 2014).

Another research question (research question four) was: Do athletes that play on a third of the field (LCR) have a different SA than an athlete that plays on a different third of the field? To investigate this question the primary investigator ran an ANOVA between SA and positions on the field (LCR). The results of that ANOVA showed that there was no statistical significance between SA and position on the field ($F(2, 52) = 1.78$, $p = 0.18$, $\omega = 0.17$). Interestingly enough, the comparison of average SA showed that the SA of center positioned athletes had a more negative SA than left positioned athletes (see Table 10.).

Table 10. LCR vs. Average SA

Average SA vs LCR				
	Men	**Women**	**Total**	**N**
Left	0.50 ± 2.09	0.78 ± 2.41	-0.32 ± 2.31	11
Center	0.57 ± 1.81	-1.52 ± 2.67	-0.92 ±2.58	28
Right	2.23 ±4.89	-0.48 ± 2.27	1.00 ± 4.00	14

This finding is interesting because hypothesis one stated that players that were positioned on the left or right-side of the field or court would have a larger SA than players that were positioned in the center. Larger is defined as values that are further away from zero or the line of symmetry. Table 10 shows the average SA of participants that were positioned LCR. Although the right-side positions did have a positive and the largest (most positive) value, the left-side and the center positions both had negative values. Even more interesting the center position group had larger (more negative) values than the left-side positions.

The second hypothesis of this study was that both MS and WS (LB) would have a different SA than the other sports of BB, SB, and VB (UB). This was a hypothesized because the BS was a lower body exercise, and the MS and WS (LB) have a specific skill movement located in the LB which was more developed than VB, SB, and BB (UB) group. That concept of the LB group having better lower body skill is referred to as specificity. The principle of specificity refers to the effect that exercise or training in general is specific to the muscles that are involved in the activity (Baechle & Earle, 2008). The LB group is more skilled in their LB because kicking is the identifying skill. It was hypothesized that the LB group would have a different SA than the UB due to specificity of training (Baechle & Earle, 2008). Table 5 displays the average SA of the two groups. The results of the independent t-test between UB and LB groups showed that there was statistical significance with a medium effect size ($p = 0.03$, $r = 0.31$) (see Appendix E: Independent t-test). This means that unlike research question two (which the researcher built the study around, position on the field and how it relates to SA in athletes), upper body sports and lower body sports affected the average SA of the participants differently. The average SA of the UB group = 1.12 ± 2.31 percent, while the average SA of the LB group = -0.69 ± 3.35 percent, meaning that the UB group favored their right-side more than the LB group. Similarly, the LB group favored their left-side more than the UB group. Therefore, the second research hypothesis: Upper body sports (VB, SB, and BB) would have a different SA than lower body sports (MS and WS) is accepted, and the primary investigator rejects the null hypothesis.

This finding means that strength and conditioning coaches could potentially implement more unilateral exercises into their resistance training programming to help combat the imbalance in the lower extremities in UB and LB sports. Unilateral exercise such as split squat, lunges, single arm rows, single arm lat pull downs and other single arm or leg exercises are ways to try and even out muscle force output (Bishop et al., 2017; Nuckols, 2015).

A highly skilled volleyball hitter that practices approximately 16 hours a week will attack (spike the ball) about 40,000 times a year with their dominate attacking arm (Kugler et al., 1996). This many spikes or attacks on that one side of the body places athletes at higher risk of developing shoulder overuse injury which is also seen in other overhead sports like BB and SB

(Kugler et al., 1996).

The most interesting question of the five in this study were: 1) Was there a difference in SA between men and women; and 3) Was there a difference in SA between sports, more specifically UB and LB sports. After running an independent t-test for differences between male and female and an independent t-test for difference between UB and LB, the results showed statistical significance in both cases. The results of the gender independent t-test were $t(51) = 2.89$, $p = 0.01$, $r = 0.37$, and the results UB/LB independent t-test $t(51) = 2.32$, $p = 0.03$, $r = 0.31$.

The average SA of the male group was asymmetric to right, meaning they favored their right-side while the average SA of the female group was asymmetric to the left, meaning they favored their left-side (see Table 5). This result is interesting because there is a statistically significant difference between the two groups. The primary investigator can only speculate that this difference correlates with the argument that men are thought to be more "power" based athletes versus women that are "finesse" based athletes (Bassey & Short, 1990; Jing, 2017; "Power of finesse in golf", 2017). The article "Power of finesse in golf" compares two volleyball games (Canadore panthers, men and women volleyball) to male and female golf matches. The article states that the women's volleyball match was mostly finesse with some power and the men's volleyball match was mostly power with some finesse ("Power of finesse in golf", 2017). The author suggests that the Ladies Professional Golf Association (LPGA) and Professional Golfers' Association (PGA) follow the same trend of men using more power and women having more finesse in sports ("Power of finesse in golf", 2017). The argument that men are more "power" based and women are more "finesse" based is not a result of asymmetry within the body but asymmetry within genders. This argument could possibly correlate with the findings of Hooper et al. (2014) and Bailey et al. (2014) that conclude that men are generally stronger than women and therefore, men can potentially utilize power more than women. This also could coincide with the SA results of this study, that men overall had a positive SA and women overall had a negative SA.

When looking at the average SA between sports, the results showed that there was a statistically significant difference in average SA between the different sports. A Tukey HSD post-hoc test revealed that the significant difference was between MS and SB ($p = 0.02$), with a trend toward significance between MS and VB ($p = 0.06$). This result is not very interesting by itself, but when you order the average SA from the least negative to the most positive, it matches the results of average SA between males and females (see Figure 23). If future research expanded this study to all sports, then all sports could potentially be ranked on a continuum. A ranking or ordering of SA could justify the strength and conditioning coaches adding unilateral movements into resistance training programs in sports or athletes that are at higher risk than others based on SA (Nuckols, 2015).

The primary investigator noticed that when comparing the UB/LB to gender, a trend devolved. UB sports tend to affect the average SA of women's sports negatively and LB sports tend to affect men's sports positively. This means that the men favored their right-side (pushed with more force), across positions played, when in a LB sport (e.g. men's soccer and women's soccer), and women favored their left (pushed with more force), across positions played, when in an UB sport (e.g. women's volleyball, baseball, and softball) (see Table 11). This phenomenon of male and female participants having different SA's agrees with the research of Bailey et al. (2014), which showed that the male group (weaker and stronger) ranged from a negative correlation to a positive correlation, while the female group showed a negative correlation in both groups (weaker and stronger) (Bailey et al., 2014). The study of Bailey et al. (2014)

investigated bilateral strength asymmetry between male and female groups and weaker and stronger groups. This study investigated the average SA between male and female and UB and LB groups. In both cases there was a trend that was present in the male group that was not present in the female group.

Table 11. UB/LB vs. Average SA

Average SA % vs Upper/Lower Groups		
	Men (N)	Women (N)
Upper	-0.11 (8)	-1.46 (23)
Lower	1.94 (11)	-0.56 (11)

The results of this study also agree with the results of Newton et al. (2006). The results of Newton et al. (2006) went against previously researched data which stated no significant bilateral strength differences in jumping track athletes. Newton et al. (2006) goes on to state that contrast in results may be because of the choice of participants. According to Newton et al. (2006), the playing and training of SB players tends to emphasize one side of the body more than the other in skills such as batting, base running and throwing. Since there was limited research on asymmetry in athletes, it is unclear if sports-specific movements are causing asymmetry in athletes, or if it was because of different factors such as injury, limb length difference or random coincidence.

Research question five looked to see if gender, sport, or positioned played could predict the SA of an athlete. After running the initial regression on sport, in the order chosen arbitrarily by the researcher, male sports entered followed by female sports (BB, MS, SB, WS, VB), the results showed no statistical significance ($r = 0.36$, $r^2 = 0.14$, $SE = 2.72$, $F(1, 52) = 3.49$, $p =$

0.07). The regression analysis of gender vs SA and position SA played on the field were also run. The results of the regression by gender (male or female) showed a medium effect size and a statistically significant correlation value ($r = 0.38$, $r^2 = 0.14$, $F(1, 52) = 8.34$, $p = 0.01$). The results of the regression by position (LCR) showed a small effect size but no statistical significance ($r = 0.14$, $r^2 = 0.02$, $F(1,52) = 0.99$, $p = 0.33$). A regression analysis of both sport and gender were run to understand if the combination of both affected the results any differently. The results of the regression of gender (male and female) and position (LCR) together showed a slightly smaller effect size and statistically significant correlation ($r = 0.39$, $r^2 = 0.15$, $F(2,52) = 4.54$, $p = 0.02$).

When the regression of sports vs SA was run in the order of the most negative mean SA to the most positive mean SA (SB, VB, WS, MS, BB) the results of the regression analysis changed to become significant ($r = 0.42$, $r^2 = 0.18$, $F(1, 52) = 10.89$, $p = 0.00$) (see Figure 23 and Appendix E). Similarly, when the order of the categories is changed within the other variables (gender and position) the level of significance was changed as well. This implies that the primary investigator could bias the outcome of the regression by manipulating the order of the groups. By ordering the groups from the most positive to least positive SA, a different threshold of significance resulted than ordering the groups arbitrarily. Therefore, the primary investigator concludes that the results of the regression are meaningless to this present study (see Appendix E: Regression Analysis). However, if future research analyzed all sports, investigators could order all sports based on how asymmetric the results were. That could potentially give justification to ranking one sport above another based on asymmetry. As far as the primary investigator's knowledge, there is no verified way to rank sports against one another.

Threshold for "High Risk"

The average SA values are not on the same spectrum of the values that would be used during the LSI or BI. Previously mentioned, values greater than 15% using the LSI or BI classify an athlete as "high risk" of injury; when using the SA to classify "high risk" of injury, the 15% value was converted to a new value (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007). This study used SA to calculate percent difference between the two limbs because this method of calculating difference is more immune to reference bias and overinflated scores when compared to LSI and BI.

According to the SA, athletes that have a SA above 4.43 percent are deemed to be at "high risk". Below is an example of two force output values that when entered into the BI equation equal "high risk", or 15% asymmetry. When the same numbers are placed into the SA equation the "high risk" values become 4.43 percent (see example below).

$$\text{Right Larger: } SI = \frac{ABS((X_{Left} - X_{Right}))}{X_{Right}} * 100$$

$$= \frac{ABS((1265 - 1100))}{1100} * 100\% = 15\%$$

$$\text{Step 1: } SA = \frac{45^{\circ} - arcTan(\frac{1265}{1100})}{90^{\circ}} * 100$$

$$\text{Step 2: } SA = \frac{45^{\circ} - 48.99^{\circ}}{90^{\circ}} * 100 = -4.43\%$$

Seven participants in this study (MS = 2, SB = 3, VB = 1, WS = 1, BB = 0) had average SA values that classify them as "high risk", values that are greater than 4.43 percent or more negative than -4.43 percent (see Appendix E: SPSS Outputs: Raw Data). Including the seven participants that classify as "high risk", there were an additional five participants that had a SA score greater than 4.43 percent or lower than -4.43 percent during one of their three trials, but their average SA did not exceed 4.43 percent or -4.43 percent. In total there were 12 participants that had a SA score that was about or below 4.43 percent and -4.43 percent respectively (MS = 3, SB = 4, VB = 2, WS = 2, BB = 1). Out of the total number of participants (N = 53), 12 were mathematically deemed as "high risk", but the primary investigator would state that there were more athletes that could be classified as "high risk". The reason why more athletes were not deemed as "high risk" was because of the flaw in the definition of BS. A majority of the current published research uses body weight jumps or single leg hops to measure asymmetry angle (Adams et al., 1992; Robbins, 2011). This study used the BS, which biomechanically is very similar to the body weight squat jump (Adams et al., 1992; Robbins, 2011). To the best of the primary investigator's knowledge, this study one of the few studies that uses the BS to measure asymmetry.

Flaw in the BS technique

In this study the BS was performed with the participant having a knee angle of 90 percent at the apex of the BS, while the hip and ankle angles were not regulated. With only one of the three joints being regulated, caused there to be a difference in true squat height from participant to participant. A participant that had a smaller ankle angle at the apex of BS had a shorter distance for the bar to travel to the apex of the BS. That distance resulted in the hip joint being above, higher than, the knee joint in most cases (see Figure 7 on page 32 and Figure 24). The participant with a larger ankle angle at the apex of the BS resulted in the hip joint being below or even parallel to the knee joint (see Figure 7 on page 32). Figure 7 shows the anterior displacement of the knee when compared to the placement of the toe. Image A in Figure 7 shows the knee tracking past the toe threshold allowing for a smaller angle at the knee during an un-restricted BS when compared to the knee angle of image B in Figure 7 (restricted BS). Figure 24 shows a side-by-side comparison of all joint angles at the apex of un-restricted back squat and restricted back squat. Image B visibly looks to be closer to 90 degrees than image A in Figure 7. The primary investigator controlled for the angle made at the knee but did not control for the anterior displacement of the knee which affected the angle at the ankle. That variance at the ankle angle possibly allowed participants to hide the true amount of asymmetry present.

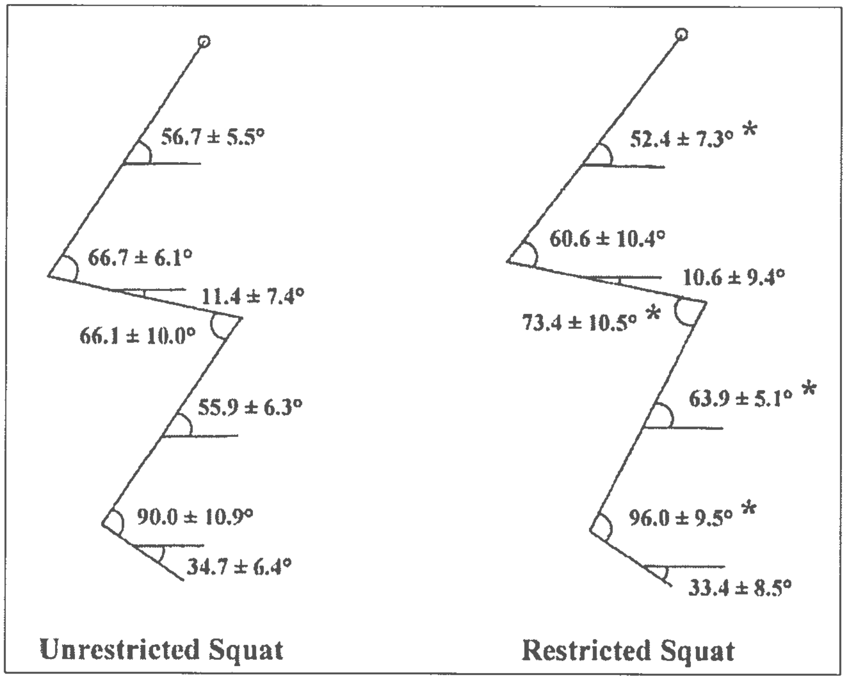

Figure 24. Restricted BS versus non-restricted BS (Fry et al., 2003).

One addition that could benefit this study is motion capture while performing the BS motion. The primary investigator noticed during data collection that some participants would physically shift their hips to one side to compensate for a biomechanical or a musculoskeletal deficiency on one side (Khuu, Foch, & Lewis, 2016). Using motion caption software, the primary researcher could note the horizontal shift, and investigate if athletes are using that shift to hide asymmetries in their force output not picked up by force plates. Khunn, Foch, and Lewis

(2016) used the commercially available software Visual 3D to measure joint angles which would simplify the data collection process of this study. For each participant, the primary research used a goniometer to measure 90 degrees at the knee and to find the depth at which each participant had to squat down to. If the primary researcher did not have to continuously change the height of the exercise band, the duration of each trial would be shorter, which would cut down on the total duration of the data collection process.

No team was in higher risk than the others with the average symmetry angles reported in the study. The teams with the highest average SA recorded were men's soccer and softball (M = 1.94 percent and -1.55 percent respectively). None of teams had an average SA that was close to the threshold of 4.43 percent set by the SA equation used by Bishop et al. (2016). It needs to be mentioned that the 4.43 percent threshold was set for an individual not a group.

Chapter 6: Summary and Conclusion

The purpose of this study was to determine if there was a correlation between lower body force exerted while performing a BS and its asymmetry in NCAA Division II athletes. Athlete participation included eight from baseball, 11 from men's soccer, 13 from softball, 11 from women's soccer and ten from volleyball. The study was delimited to these five sports because the position of these sports does not rotate between the left, center and right-sides of the field. That fact in addition to hypothesis one which stated, athletes that play on the right or left-sides of the field/court would have larger SA then centrally positioned athletes, or athletes that play in the center of the field/ court, is where the main research question of this study was derived from. With these athletes the researcher looked to investigate five main research questions during this study. The research questions were: 1) was there a relationship between position played on the field/court and SA present in athletes? 2) Was there a difference in SA between men and women? 3) Was there a difference in SA between the sports included in this study? 4) Do athletes that play on a specific third of the field (right, center, or left) have a different asymmetry angle than an athlete that plays on another third of the field? 5) Does position played, gender, or sports predict SA (asymmetry) in athletes.

The primary investigator concluded that there is not a statistically significant relationship between positions played on the field, in men or in women, and average SA present in athletes (research question 1). Similarly, the primary investigator concluded that there was no statistical significance in the difference in means of average SA between positions (left, center, or right) on the field/ court (research question 4). Research question five asked if playing position, gender or sport could predict asymmetry in athletes. The only meaningful result was that gender and average SA had a small correlation of $r = 0.38$, and that gender was responsible for 14% of the variance in average SA (see Appendix E). Separate regression analysis between sports (BB, MS, SB, WS, VB), gender (male and female), and position and sport together were run. The results of the three separate regression analyses were concluded to not be meaningful because there is no verified way to order sport, gender, and sport-and-gender. Also, if there are more than two groups, the order the variables are entered can dictate the outcome (BB = 1, MS = 2, SB = 3, WS = 4, VB = 5, r = .25, $r^2 = 0.06$, $p = 0.07$; SB = 1, VB = 2, WS = 3, BB = 4, MS = 5, r = 0.42, $r^2 = 0.18$, $p = 0.00$) (research question 5). The most interesting research questions were questions three and four, which investigated if there was a difference between men and women, and if there was a difference between the five sports when measuring average SA. The independent t-test showed that there was significant difference ($p = 0.01$) between gender when measuring average SA (Male: M = 1.07 ± 3.09 percent, Female: M = -1.17 ± 2.49 percent). The ANOVA showed that there was a significant difference between sports ($p = 0.03$), and the Tukey HSD post-hoc test revealed that the significant difference was between MS and SB ($p = 0.02$), with a trend toward significance between MS and VB ($p = 0.06$).

The results of this study showed that it was not the position on the field that influenced the lower body asymmetry, but the nature of the sport being played, whether it is an UB sport or a LB sport, that influences the lower asymmetric force output. Not only did that grouping variable influence the lower body force output, but it had opposite effects on gender, men having a positive average SA and the women having a negative average SA. This was very similar to the results of Bailey et al. (2014) who found two different correlations between groups (stronger group and weaker group) when comparing men and women. It is not understood why there was a difference between male and female participants, and why the distinction of UB and LB sports also seemed to affect the results of the participants. Perhaps it has something to do with the argument of men are thought to be more "power" based athletes versus women that are more "finesse" based athletes (Bassey & Short, 1990; Jing, 2017; "Power of finesse in golf,"2017). This argument could potentially correlate with the argument that men are generally stronger than women which allows them to utilize power more than women (Bailey et al., 2014; Hooper et al., 2014).

Practical Applications

The results of this study can be of practical benefit to athletes and coaches, and strength and conditioning coaches and team coaches alike. Having an asymmetric difference of 15% or greater can place an athlete in a "high risk" for injury. If a strength and conditioning coach is aware of the asymmetry and can tailor training programs to counteract that asymmetry, whatever may be causing it (type of sport: UB/LB, and/or gender), then athletes potentially could have healthier and longer athletic careers (Bell et al., 2014; Hewit et al., 2012; Impellizzeri et al., 2007). It is important to note that the correction of imbalances can be beneficial to an athlete's health, and lessen their risk of injury but it may not increase an athlete's physical performance (Bishop et al., 2017).

The non-significant results of positioning on the field/court suggests that the argument could be made that allows coaches to not worry about specific athletes and their position background. This means that an athlete that has been playing on one side the field/ court doesn't have a higher risk of being injured than an athlete that plays multiple positions that land them on different thirds of the field/court. The results of this study begin the argument that depending on the sport that is being coached, these coaches could possibly pre-emptively put the athletes on their team through a strength and conditioning program designed to correct asymmetry or to maintain levels of asymmetry present.

The results of this study also start a discussion on how to order all sports on a scale of "high risk" or not at "high risk" (see Figure 23). If future research collected and analyzed data for all teams then there may be a logical way to rank sports for risk of injury other than number of injuries from previous years (Loes, Dahlstedt, & Thomee, 2000).

Future Research

This study looked at five team sports that have positions that were restricted to parts of their field or court, and the average number of participants per team was just over ten participants during the team sports' off-season. Each participant was tested individually for an average of approximately 15 minutes and then were released. The BS was performed at 70% of each participant's 1RM. At the conclusion of the test the athlete was told his/her score, and it was explained what the scores meant to the primary investigator and what that can mean for the participant. An example of what the results could mean to the athlete is that the athlete favors one leg over the other. It is then up to the athlete and coaches to understand if that could potentially be a benefit or something that needs to be corrected.

Study Participation

Future research in SA could benefit from the inclusion of all sports and different level of sports. This study only looked at the results of five different sports: BB, MS, VB, SB, and WS. This could include sports such as hockey, football, and lacrosse, sports that have positions that are not restricted to a portion of the field. Also, it could include youth sports and high school sports, to see if age and experience playing the position, or experience lifting weights has an effect on average SA. This study had an average participant per team of N = 10.6. Analyzing data from a sub-group of ten or less does not leave the primary investigator with very much statistical power when analyzing sub-groups. This results in large variances and rather large standard deviations. Future research should look into possibly having a greater N per team to negate that problem and create larger statistical power. Having about twenty participants per sub-group may give more statistical power. Also, having more participants in each sub-group may keep outliers from skewing the data so heavily.

Methodology

Future research could benefit from incorporating motion capture analysis while performing the BS. This study only looked at force plate data for each participant to calculate SA. A common issue that the primary investigator noted during data collection was an off-set of force output peaks during the eccentric-concentric phase crossover (see Figure 25). This means that the two force plates read peak force (N) at different times, granted only milliseconds different, but still different times. This leaves the primary investigator with no way to justify when maximum force was exerted during the squat. In this study, if the force output peaks were off-set, the force output peak that was recorded first (right or left) was recorded and the second value was taken within 0.01 seconds on either side of the first recorded peak. With motion capture software the primary investigator can have concrete data saying when the BS happened in time with the change in direction in the vertical velocity of each participant.

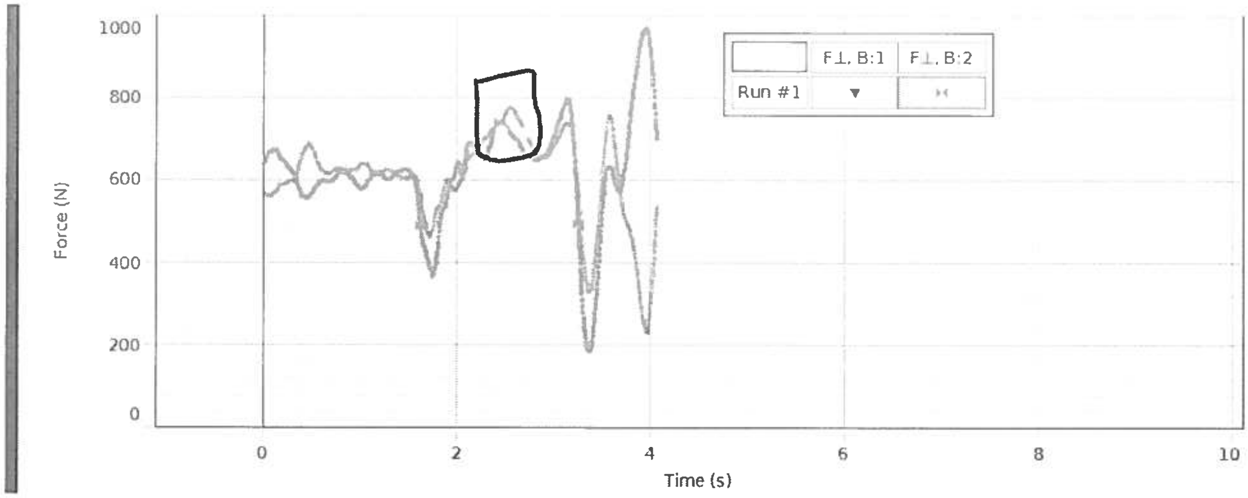

Figure 25. Subject VB0519, peak force at different times.

Future research could also benefit from motion capture analysis with the ability to distinguish when the BS happened in real time. Occasionally in this study, a participant would perform a BS while not exerting a lot of power making it difficult to see the phases of the BS on the graph (see Figure 26).

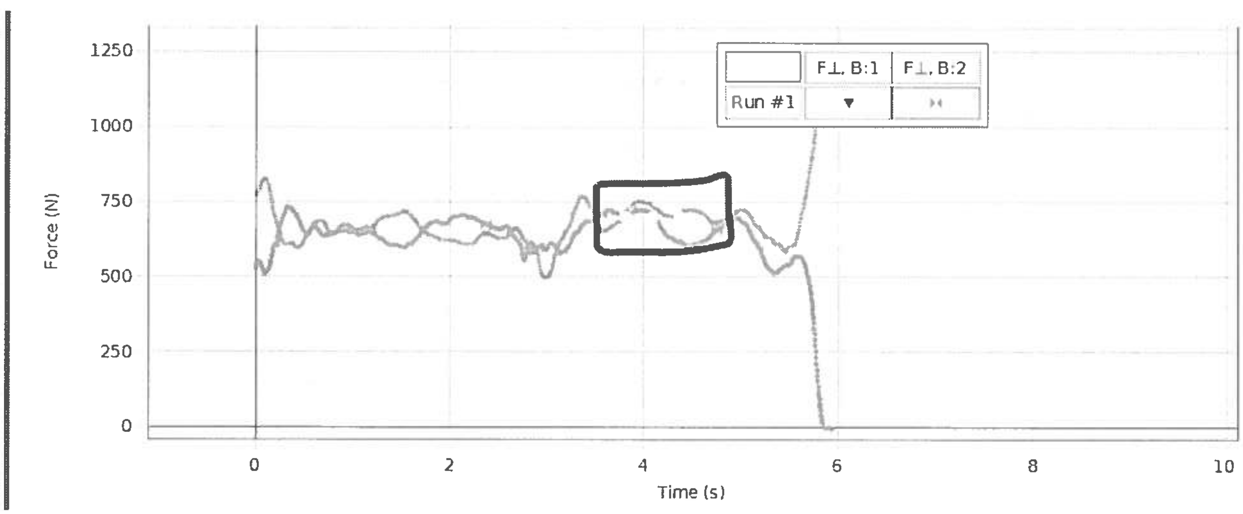

Figure 26. No-distinct peak, participant WS1041.

This leads to the conclusion that the addition of motion capture analysis could potentially clear up all issues in this data collection. The possibility of adding a horizontal asymmetry component to the study could potentially be an interesting avenue to explore. With motion capture analysis, researchers could track the horizontal displacement of the bar and determine if it correlates to symmetric outcome values. With motion capture analysis, researchers could also determine if greater horizontal displacement causes a participant to be feel unstable while performing the BS. The researcher could compare those results to the results of Lawrence and Carlson (2015) who investigated the effects of an unstable load on force and muscle activation during a parallel BS.

Future research could potentially duplicate this study but use an upper body movement to measure asymmetry in the upper body then compare the results of the UB/LB groups of this study to see if the type of test biased the results of the groups. Also, would the significance between gender change with the change in the movement tested? This study used a lower body test to measure asymmetry in sports that had their defining action in both the upper body (BB, SB, VB) and lower body (MS, WS). If future research used an UB movement and compared the same grouping of sports (UB/LB), would the results be similar?

Future research could possibly add upper body sports that have a defining action that is not solely performed on one side of the body (e.g. martial arts, boxing, and rugby). These sports have actions that are specific to their sports like striking, punching, and under handed throwing but, unlike other sports, these actions are done on both sides of the body. Would the results of the SA being measured by an upper body movement be similar or consistent with the results of SA measured by a lower body movement?

Conclusion

This study investigated asymmetry in athletes and the possibility of what causes asymmetry in athletes. There were five research questions in this study: 1) Is there a difference in SA between sports? 2) Is there a relationship between position played on the field and SA present in athletes? 3) Is there a difference in SA between men and women? 4) Do athletes that play on a specific third of the field (RCL) have a different asymmetry angle than an athlete that plays on another third of the field? 5) Does position played on the field, gender, sport played predict asymmetry in athletes? It was also hypothesized that: 1) Athletes that played on the right or left-side of the field/court would have larger (more negative or more positive) SA than athletes that played in the center of the field/ court; and 2) LB athletes (MS and WS) would have a different SA than UB (VB, BB, and SB) athletes. In total, 53 athletes participated in this study. The athletes were divided in to different sub-groups depending on the comparison. The groups included: sports, UB/ LB, INT/EXT and gender. Results showed statistically significant results when comparing average SA between gender, UB/LB, and sports ($p < 0.05$). After the analysis of the data, hypothesis 1, the difference between INT and EXT players when analyzing average SA, was not accepted; however, hypothesis 2, the difference between UB and LB sports when analyzing average SA, was accepted. The primary investigator suggests the addition of motion capture, eliminating the delimitation of using sports that have athletes that stay on one side of the field the majority of the time, and have more athletes per sub-group to clear up issues that were seen during data collection in this study.

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Appendices

Appendix A: Email to Head Coaches

Dear Mr./s

My name is Uchenna Ogbonnaya, and I am graduate student perusing my Master of Science in the Department of Human Performance and Physical Education (HPPE). I am reaching out to you, to ask your permission to ask your athletes to participate in a study that I am the lead researcher for my thesis research project.

The purpose of this study is to determine if there is a relationship between lower body force output asymmetry, and positioning on the field due to unique repetitive sports movements. This will be done by measuring force output while performing a barbell back squat (BS) in NCAA Division II collegiate men's and women's soccer, volleyball, baseball and softball players.

Each participant will perform 3 BS's at 70% of their 1RM while standing on force plates to measure their force output of each leg. Once the athlete has performed three BS, the athlete will be briefed on what the numbers mean and then the athlete will be free to go. The total time required to participate in the study will be approximately 30 minutes.

If you have any questions, please do not hesitate to call me at 612-203-1272 or email me at Ogbonnayauc@grizzlies.adams.edu.

Thank you for your time!

Uchenna C Ogbonnaya, CSCS
Adams State University
Graduate Assistant Coach for Women's soccer
Graduate Assistant Strength and Conditioning Coach
(c) 612.203.1272

Appendix B: Data Score Card

Name: ____________________ ID Number: ____________________

Date: ____________________ Age (Years) ____________________

Number: ____________________ Email: __________________________

Gender: ____ Dominate hand (R/L): ________ Are you in full health currently? (Y/N) ________

Sport Played: __________ Years playing that sport _________Position in sport: ___________

Exp. Lifting (Yrs.): ___________ Back Squat 1RM: ________

Height (cm): ____ Weight (kg): _____

Participant ID Number:	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
Peak Force (N) Right:						
Peak Force (N) Left:						

Appendix C: Institutional Review Board Request Form

Adams State University

Request to obtain expedited approval for the use of human participants

Date: March 23, 2018

To: Penny Sanders, Chair of the ASU Institutional Review Board

Name: Uchenna C Ogbonnaya
Email: Ogbonnayauc@Grizzlies.adams.edu
Address: 80 El Rio Drive A, Alamosa CO 81101
Phone: 612-203-1272
Responsible Faculty Member: Tracey Robinson, Ph.D.
Email: tlrobins@adams.edu

Subject:

Human Performance: Biomechanics

Others in Contact with Human Participants:

The primary researcher, Head Strength and Conditioning Coach Matt Gersick and possibly Graduate HPPE student Shelby McBain, Alex Jordan, Kris Mugrage.

The title of the research:

"Asymmetric lower body force output while performing a barbell back squat in NCAA Division II athletes"

Objectives of the research:

Being a complete/ well-rounded athlete is a universal goal for all athletes. An athlete who is completely balanced, or symmetric, across all athletic attributes necessary or lacking in deficient category will make an athlete more desirable to coaches and teammates. With that said, any athletes have a deficiency, or are asymmetric somewhere in their skill set, whether it be physical or physiological (McCaw & Bates., 1991; Newton et al., 2006). For example, a physical asymmetry could be the tendency to only move to the athlete's left, and a physiological imbalance could be constant dehydration, or nutritional imbalance (anorexia or bulimia). A common asymmetry in athletes is a mechanical asymmetry (McCaw & Bates., 1991; Newton et al., 2006). If an athlete is not mechanically balanced, there will then be a tendency to favor the dominant side over the mechanically weaker side, and could be categorized as "high risk" for injury depending on the severity (Bell, Sanfilippo, Binkley, & Heiderscheit, 2014; Hewit, Cronin, & Hume, 2012; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007). In the example of soccer players and their ability to kick the ball, the inability to kick with both feet can make an athlete one-dimensional thus creating a mechanical imbalance and decreasing their overall ability to perform. If an athlete is weaker on one side of their body, that side of the body can fail before the other side and become injured, especially in the case of repetitive sports (Newton et al., 2006). If this asymmetry can be corrected in athletes, they may be generally healthier and it may potentially increase their overall ability to perform as an athlete. This study will explore asymmetry in lower body force output in athletes. The purpose of the study is to try to identify if asymmetry is caused by repetitive sports-specific movements because of the position played on the field, in soccer, volleyball, baseball, and softball players.

Methods of procedure:

The researcher will attain approval by the IRB prior to the start of the study. Once approval has been granted to the researcher, the researcher will ask volleyball, soccer (men's and women's), baseball, and softball teams via email, asking for permission to talk to the teams and brief them on the experiment. Once briefed, any athletes that want to participate will sign the IRB consent form and schedule an appointment time. On the date and time of the previously set up appointment the participants (one at a time), will arrive at the Human Performance lab. Each participant will then fill out a data score card asking questions including name, email, age, gender, sport, primary position, how long they have played said position (minimum one year required for inclusion), years of experience weight lifting (minimum of one year required for inclusion), and last known back squat (BS) 1 repetition max (1RM) within the last calendar year. The 1RM will be checked against the records of the head strength & conditioning coach at the university. In the situation of an athlete not having a BS 1RM (i.e. a mid-year transfer or an athlete that was missing the day 1RMs were recorded), that athlete will not proceed any further in the research.

After completion of the data form, the participants will have their basic anthropometric data taken, which includes height (cm) and weight (kg). Following the measurements, the participant will begin a standard 5-minute warm-up on a stationary bike, located in the Human Performance lab. After the warm-up the participant will move to the Strength and Conditioning lab. The participant will then perform one warm-up set of eight reps at 50% of their 1RM of the BS. Before the participant performs this warm-up set, the researcher will inform the participant on proper BS technique and brief him or her on the BS protocol, allowing a few reps to practice reaching appropriate depth for a successful BS (see back squat protocol). Note: the researcher will demonstrate proper BS technique. During the warm-up and test itself, if a knee angle, measured by a goniometer, of 90-degrees is not met, the rep will not count. The participant can perform up to three unsuccessful reps, before a failed test. This means a maximum of six reps can be done to prevent reaching fatigue. Fatigue for this study will be when the reps within a set are more than seven reps. After seven reps the participant's trunk, knee, and ankle angles tend to begin to change due to self-preservation (Hooper et al., 2014). If the participant has not completed three successful reps by the 6th rep, the test will be over and that participant's data will not be included in the analysis.

After the warm-up, a three-minute break will be given to ensure full recovery. After calibration of the force plates, the researcher will start the data collection by asking if the participant is ready to begin. After an audible confirmation, the participant will be asked to step on to the two force plates and perform a BS. The participant will step on to the two force plates, then lift a barbell off the squat rack that has been loaded with the correct amount of weight by the researcher with 70% of the participant's 1RM. If 70% 1 RM is not a weight that can be loaded, because the weight is not an increment of five pounds, then an increment of five pounds closest to and below 70% of 1RM will be used for the safety of the participant.

The participant will perform a proper BS, then rack the weight on the squat rack and step off the two force plates; the subject will rest a minimum of one minute before performing that task again. The participant will perform a 70% 1RM squat a total of three successful times. The two force plates will collect data during both the eccentric and concentric phases of the BS movement during each rep.

Once the participant has finished, the participant will be briefed with an explanation of the initial raw data, and its meaning and significance will be explained and then the participant will be free to leave. The total time commitment for participating in the study is approximately 20-30 minutes.

Back squat protocol/ technique. The BS protocol is as follows:

The researcher will explain, and walk the participant through how to un-rack the barbell during the participants warm up, see section below. Once ready, the participant will enter the Rogue squat rack, step on to the two force plates, and un-rack the weight. Prior to performing the BS, the participant will wait for an audible signal by the researcher to ensure that the software is ready to collect the data. Once the researcher gives the go-ahead, the participant will perform the BS.

The BS motion begins with the knees and the hips fully extended. Hips and feet should be in a straight line, and both feet should be parallel and even to each other (not staggered). Next the participant will descend the weight in a controlled manner at a velocity that is comfortable for the participant until a 90-degree angle is reached at the knee joint. Then the participant drives the weight in the upward direction until the participant reaches full extension in the hips and knees. Then the participant will pause briefly, allowing the researcher to stop the force plate software, and then re-rack the barbell (see section below). The researcher will confirm the 90-degree knee angle by measuring with a goniometer during the warm-up reps. The researcher will assess the 90-degree knee angle with a goniometer, then find the height from the floor to the gluteus maximus where that 90-degree knee angle is met. The researcher will set the safety catches on the Rogue squat rack to that height and place an elastic band across the safety catches to give the participant a physical cue when they have reached a proper BS depth. The participant will only touch the elastic band and should not squat any deeper since the elastic nature of the band can possibly help the participant ascend the weight vertically and skew the reading by the force plates.

During the BS movement, the participant should try to keep their trunk upright during the whole movement. It is important to note that there will be some forward lean at the bottom position of the BS. Since the researcher is not measuring forward lean in the trunk, forward lean will not exclude a participant from the study if a knee angle of 90 degrees is measured by the goniometer.

Un-racking/ Re-racking the barbell

To begin the participant will straddle the force plates (one foot in front and one foot behind the force plate) and place both hand on the barbell evenly spaced from the center of the barbell. Then the participant will position themselves under the barbell aligning the barbell so it sits on the upper shoulder and trapezius area of the back. Note: if the participant has longer hair it may be more comfortable to move hair out of the way of the barbell so the barbell does not pinch or catch the hair. Once positioned under the bar the participant will then bring both feet forward in front of both force plates. Using their legs to lift the bar of the Rogue squat rack then carefully stepping back on to the force plates (there is approximately a two inch step up on to the force plates). The researcher or CPR/AED certified assistant will be spotting the participant. Once the BS is complete the participant will step and lean forward and place to re-rack the barbell.

Protection Measures:

Participation is voluntary and identifying information will be held confidential. Participants may choose not to answer any question they do not want to answer and/or may withdraw from participating at any time without any penalty. Names will not be used in the study; participants will be assigned an identification number. The hard copy of the data will be destroyed after being digitized, and then will be stored in a password protected folder on the researcher's computer and also on a backup on a password protected online server for at least three years, where only the primary researcher will have access to the raw digitized data. If the research is used in a public form, the data will be reported as a group without individual identification.

Benefits to the Individual

If you agree to participate in this study, the main benefit will be a deeper understanding of your athletic body. This means you will know if you have an asymmetry in your lower body and to what degree that asymmetry is, and if need be you and possibly a strength and conditioning coach or specialist can go and target this asymmetry to make you a more well-rounded and balanced athlete. Simply being presented with the degree that you may or may not be asymmetric will not increase your athletic ability. However, your participation will contribute to future research in the topic of lower body force asymmetry.

Risks to the Individual

There are some risks and discomforts associated with participation in research of this manner. When performing a barbell back squat at a submaximal load such as 70% of 1RM there is a chance of getting delayed onset muscle soreness (DOMS) up 72 hours after performing the barbell back squat. DOMS is not life threatening; DOMS only encompasses localized soreness and discomfort. This soreness and small potential risk of injury is not any more than an athlete would encounter in normal training The BS protocol is similar to that of Gullet et al. (2009), and has also been cleared by the head strength and conditioning coach, Matt Gersick

Confidentiality

All information received in this study is confidential. Participant information will be kept in a locked desk drawer, a locked filing cabinet, or a password protected electronic file, and only the primary researcher and thesis committee members will have access to demographic forms, or any raw data and will only be disclosed with your written permission as required by law. No names will be associated with participants in the study. All information will be destroyed after three years.

Consent

Participants will be asked to read over and sign the consent form before any testing begins. The informed consent is attached separately.

Changes

If any changes are made to the research, the researcher will contact the IRB immediately and fill out the needed paperwork.

Name and Signature of Department Chair or IRB Area Representative — Date: 6-13-17

Name and Signature of IRB chair — Date: 6.6.17

ADAMS STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
Approved on: 6-6-2017
Expires on: 6-6-2018

Appendix D: Informed Consent for Asymmetric Lower Body Force Output Study

RESEARCH PARTICIPANT CONSENT FORM

Asymmetric Lower Body Force Output While Performing a Barbell Back Squat in NCAA Division II Athletes

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Purpose of Research
The purpose of the current study is to explore the correlation between lower body force asymmetry with repetitive sports movements by measuring force output while performing a barbell back squat (BS) in NCAA Division II collegiate athletes who participate in sports that have a left, right or center specification to the playing positions (i.e. soccer, volleyball, baseball, and softball).

Summary of Specific Procedures to be Used
One at a time, the athlete (you) will arrive at the Human Performance lab to fill out a data score card asking questions including name, email, age, gender, sport, primary position, how long they have played said position (minimum one year required for inclusion), years of experience weight lifting (minimum of one year required for inclusion), and last known BS 1 repetition max (1RM) within the last calendar year. The 1RM will be checked against the records of the head Strength & Conditioning coach at the university. In the situation that an athlete does not have a BS 1RM (i.e. a mid-year transfer or an athlete that was missing the day 1RMs were recorded), the athlete will not proceed any further in the research.

After completion of the data form, the participants will have their basic anthropometric data taken, which includes height (cm) and weight (kg). Following the measurements, the participant will begin a standard 5-minute warm-up on a stationary bike, located in the Human Performance lab. After the warm up the participant will then move to the Strength and Conditioning lab. The participant will then perform one warm-up set of eight reps at 50% of their 1RM of the BS. Before the participant performs this warm-up set, the researcher will inform the participant on proper BS technique and brief him or her on the BS protocol, allowing a few reps to practice reaching appropriate depth for a successful BS (see back squat protocol). Note: the researcher will demonstrate proper BS technique. During the warm-up and test itself, if a knee angle, measured by a goniometer, of 90-degrees is not met, the rep will not count. The participant can perform up to three unsuccessful reps, before a failed test.

This means a maximum of six reps can be done to prevent reaching fatigue. Fatigue for this study will be when the reps within a set are more than six reps. After six reps the participant's trunk, knee, and ankle angles tend to begin to change due to self-preservation (Hooper et al., 2014). If the participant has not completed three successful reps by the 6th rep, the test will be over and that participant's data will not be included in the analysis.

After the warm-up, a three-minute break will be given to ensure full recovery. After calibration of the force plates, the researcher will start the data collection by asking if the participant is ready to begin. After an audible confirmation, the participant will be asked to step on to the two force plates and perform a back squat. The participant will step on to the two force plates, then lift a barbell off the squat rack that has been loaded with the correct amount of weight by the researcher with 70% of the participant's 1RM. If 70% 1 RM is not a weight that can be loaded, because the weight is not an increment of five pounds, then an increment of five pounds' closets below to 70% of 1RM will be used for the safety of the participant.

The participant will perform a proper BS, then rack the weight on the squat rack and step off the two force plates; the subject will rest a minimum of one minute before performing that task again. The participant will perform a 70% 1RM squat a total of three successful times. The two force plates will collect data during both the eccentric and concentric phases of the BS movement during each rep.

Once the participant has finished, the participant will be briefed with an explanation of the initial raw data, and its meaning and significance will be explained and then the participant will be free to leave. The total time commitment for participating in the study is approximately 20-30 minutes.

Back Squat Protocol/ Technique. The BS protocol is as follows:
The researcher will explain, and walk the participant through how to un-rack the barbell during the participant's warm-up, see section below. Once ready, the participant will enter the Rogue squat rack, step on to the two force plates, and un-rack the weight. Prior to performing the BS, the participant will wait for an audible signal by the researcher to ensure that the software is ready to collect the data. Once the researcher gives the go-ahead, the participant will perform the BS.

The BS motion begins with the knees and the hips fully extended. Hips and feet should be in a straight line, and both feet should be parallel and even to each other (not staggered). Next the participant will descend the weight in a controlled manner at a velocity that is comfortable for the participant until a 90-degree angle is reached at the knee joint. Then the participant drives the weight in the upward direction until the participant reaches full extension in the hips and knees. Then the participant will pause briefly, allowing the researcher to stop the force plate software, and then re-rack the barbell (see section below). The researcher will confirm the 90-degree knee angle by measuring with a goniometer during the warm-up reps. The researcher will assess the 90-degree knee angle with a goniometer, then find the height from the floor to the gluteus maximus where that 90-degree knee angle is met. The researcher will set the safety catches on the Rogue squat rack to that height and place an elastic band across the safety catches to give the participant a physical cue when they have reached a proper BS depth. The participant will only touch the elastic band and should not squat any deeper since the elastic nature of the band can possibly help the participant ascend the weight vertically and skew the reading by the force plates.

During the BS movement, the participant should try to keep their trunk upright during the whole movement. It is important to note that there will be some forward lean at the bottom position of the BS. Since the researcher is not measuring forward lean in the trunk, forward lean will not exclude a participant from the study if a knee angle of 90 degrees is measured by the goniometer.

Un-racking/ Re-racking the Barbell

To begin the participant will straddle the force plates (one foot in front and one foot behind the force plate) and place both hand on the barbell evenly spaced from the center of the barbell. Then the participant will position themselves under the barbell aligning the barbell so it sits on the upper shoulder and trapezius area of the back. Note: if the participant has longer hair it may be more comfortable to move hair out of the way of the barbell so the barbell does not pinch or catch the hair. Once positioned under the bar the participant will then bring both feet forward in front of both force plates. Using their legs to lift the bar of the Rogue squat rack then carefully stepping back on to the force plates (there is approximately a two inch step up on to the force plates. The researcher or CPR/AED certified assistant will be spotting the participant. Once the BS is complete the participant will step and lean forward and place to re-rack the barbell.

Duration of Participation

Your participation in this study will include a warm-up, explained above, then performing three reps at 70% of your one repetition max of the BS on two individual force plates by means of a squat protocol. The two force plates will be collecting the amount of force exerted upon them by you the participant in real time. The total time to complete this study will be approximately 20 minutes per participant.

Benefits to the Individual

If you agree to participate in this study, the main benefit will be a deeper understanding of your athletic body. This means you will know if you have an asymmetry in your lower body and to what degree that asymmetry is, and if need be you and possibly a strength and conditioning coach or specialist can go and target this asymmetry to make you a more well-rounded and balanced athlete. Simply being presented with the degree that you may or may not be asymmetric will not increase your athletic ability. However, your participation will contribute to future research in the topic of lower body force asymmetry.

Risks to the Individual

There are some risks and discomforts associated with participation in research of this manner. When performing a barbell back squat at a submaximal load such as 70% of 1RM there is a chance of getting delayed onset muscle soreness (DOMS) up 72 hours after performing the barbell back squat. DOMS is not life threatening; DOMS only encompasses localized soreness and discomfort. This soreness and small potential risk of injury is not any more than an athlete would encounter in normal training The BS protocol is similar to that of Gullet et al. (2009), and has also been cleared by the head strength and conditioning coach, Matt Gersick

Compensation

There will be no compensation for participating in this study.

Confidentiality

All information received in this study is confidential. Participant information will be kept in a locked desk drawer, a locked filing cabinet, or a password protected electronic file, and only the primary researcher and thesis committee members will have access to demographic forms, or any raw data and will only be disclosed with your written permission as required by law. No names will be associated with participants in the study. All information will be destroyed after three years.

Contact Information Statement

Primary Researcher	IRB Chair	Committee Chair
Name: Uchenna Ogbonnaya	Name: Dr. Penny Sanders	Name: Dr. Tracey Robinson
Email: Ogbonnayauc@grizzlies.adams.edu Phone: (612)203-1272	Email: Pennysanders@adams.edu Phone: (719)587-8413	Email: Tlrobins@adams.edu Phone: (719)587-7663

Human Subject Statement
If you have any questions regarding your rights as a participant in this research and/or concerns about the study, or if you feel under any pressure to enroll or to continue to participate in this study, you may contact Adams State University Institutional Review Board (which is a group of people who review the research studies to protect participants' rights) at Penny Sanders Pennysanders@adams.edu or (719)587-8413.

You may ask more questions about the study at any time. For questions about the study contact Uchenna Ogbonnaya at Ogbonnayauc@grizzlies.adams.edu or (612)-203-1272.

A copy of this consent form will be given to you to keep.

Voluntary Nature of Participation
"I understand that I can withdraw my participation at any time and will not suffer a penalty of any kind doing so."

"I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT."

______________________________ ______________________
Participant's Signature Date

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Participant's Printed Name

______________________________ ______________________
Researcher's Signature Date

ADAMS STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
Approved on: 6-6-2017
Expires on: 6-6-2018

Appendix E: SPSS Outputs

Descriptive

Descriptive

Average Symmetry Angle

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Baseball	8	-0.1120	1.37796	0.48718	-1.2640	1.0400	-1.96	2.12
Men's Soccer	11	1.9400	3.72787	1.12400	-0.5645	4.4444	-1.74	9.59
Softball	13	-1.5502	2.62191	0.72719	-3.1346	0.0342	-5.19	2.23
Women's Soccer	11	-0.5551	2.49145	0.75120	-2.2288	1.1187	-5.91	2.70
Volleyball	10	-1.3520	2.43861	0.77116	-3.0965	0.3924	-4.47	3.27
Total	53	-0.3648	2.90127	0.39852	-1.1645	0.4349	-5.91	9.59

Data Analysis Descriptive

	(N)	Min	Max	Mean	Std. Dev.
Age (years)	53	18	23	20.19	1.257
Height (cm)	53	148	194	169.5849	9.28799
Weight (kg)	53	50	93.5	70.5283	10.91903
Exp. playing position (years)	53	1	19	9.06	4.483
Exp. lifting (years)	53	1	11	5.16	2.461
SA Trial 1 (percent)	53	-8.07	11.11	-0.3258	3.82638
SA Trial 2 (percent)	53	-7.97	8.23	-0.2639	2.96991
SA Trial 3 (percent)	53	-9.89	9.55	-0.5183	3.56848
SA Average (percent)	53	-5.91	9.59	-0.3648	2.90127

Data Analysis Descriptive Male					
	(N)	Min	Max	Mean	Std. Dev.
Age (years)	19	18	23	21	1
Height (cm)	19	165	194	174	9.08
Weight (kg)	19	56	90.50	73.74	8.76
Exp. playing position (years)	19	2	19	9	5
Exp. lifting (years)	19	2	11	6	3
SA Trial 1 (percent)	19	-4.69	11.11	1.18	3.84
SA Trial 2 (percent)	19	-3.89	8.23	1.13	3.36
SA Trial 3 (percent)	19	-2.70	9.55	.93	3.35
SA Average (percent)	19	-1.96	9.59	1.08	3.09

Data Analysis Descriptive Female					
	(N)	Min	Max	Mean	Std. Dev.
Age (years)	34	18	22	20	1
Height (cm)	34	148	190	166.68	8.17
Weight (kg)	34	50	93.50	68.74	11.70
Exp. playing position (years)	34	1	18	9	4
Exp. lifting (years)	34	1	10	5	2
SA Trial 1 (percent)	34	-8.07	6.63	-1.17	3.61
SA Trial 2 (percent)	34	-7.97	3.55	-1.04	2.45
SA Trial 3 (percent)	34	-9.89	3.81	-1.33	3.47
SA Average (percent)	34	-5.91	3.27	-1.17	2.49

	Experience lifting (yrs.) ± SD	Experience in Position (yrs.) ± SD	Back Squat 1RM ± SD	Height (cm) ± SD	Weight (kg) ± SD	Average SA (percent) ± SD	Total Participation in Sport (N)
Upper Body group	5±2	9±4	210±54	170.53±9.54	72.73±11.22	-1.12±2.31	31
Lower Body Group	5±2	9±5	215±48	168.25±8.97	67.43±9.91	.69±3.35	22
Internal Group	5±3	10±4	206±50	170.45±11.47	69.58±9.81	-.92±2.58	28
External Group	5±2	8±5	219±53	168.62±6.09	70.53±10.92	.26±3.16	25
Male group	6±3	9±5	256±50	174.79±9.08	73.74±8.76	1.08±3.09	19
Female Group	5±2	9±4	187±31	166.68±8.17	68.74±11.70	-1.17±2.90	34

Group Statistics

Left vs Right		N	Mean	Std. Deviation	Std. Error Mean
Average Symmetry Angle	Left	14	-0.3210	2.30722	0.61663
	Right	11	0.9973	4.00225	1.20673
Internal vs External		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Average Symmetry Angle	Center	28	-0.9218	2.57624	0.48686
	Exterior	25	0.2590	3.16286	0.63257
Upper Vs Lower		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Average Symmetry Angle	Upper	31	-1.1151	2.31213	0.41527
	Lower	22	0.6924	3.34722	0.71363
Upper Vs Lower		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Average Symmetry Angle	Upper	31	-1.1151	2.31213	0.41527
	Lower	22	0.6924	3.34722	0.71363
Gender		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Average Symmetry Angle	Male	19	1.0760	3.08907	0.70868
	Female	34	-1.1700	2.48912	0.42688

Breakdown of the Groups on Each Team

	Left side participants (N)	Center Participation (N)	Right Side Participation (N)	Total Participation in Sport (N)	Experience lifting (Yrs.) ± SD	Experience in Position (Yrs.) ± SD	Back Squat 1RM ± SD	Height (cm) ± SD	Weight (kg) ± SD	Average SA (percent) ± SD
Baseball	1	5	2	8	7 ± 3	7 ± 3	282 ± 41	176.75 ± 9.41	76 ± 63	-0.11 ± 1.38
Men's Soccer	4	3	4	11	6 ± 2	11 ± 6	237 ± 49	173.36 ± 9.00	71.64 ± 9.39	1.94 ± 3.73
Softball	5	8	0	13	4 ± 2	10 ± 5	192 ± 26	163.23 ± 5.15	67.23 ± 12.26	-1.55 ± 2.62
Women's Soccer	2	7	2	11	5 ± 3	8 ± 4	193 ± 36	163.14 ± 5.51	63.23 ± 8.89	-0.56 ± 2.49
Volleyball	2	5	3	10	5 ± 2	9 ± 3	175 ± 31	175.05 ± 8.07	76.75 ± 10.08	1.35 ± 2.44
Total	**14**	**28**	**11**	**53**	**5 ± 2**	**9 ± 4**	**70.53 ± 10.92**	**169.58 ± 9.29**	**212 ± 51**	**-.36 ± 2.90**

Interior/ Exterior Position by Sport

	Exterior Participants (N)	**Interior Participants (N)**	**Total (N)**
Baseball	3	5	8
Men's Soccer	8	3	11
Softball	5	8	13
Women's Soccer	4	7	11
Volleyball	5	5	10
Total	**25**	**28**	**53**

Independent T-Test

Independent Samples Test Between Gender Male and Female

		Levene's Test for Equality of Variances		t-test for Equality of Means							
									95% Confidence Interval of the Difference		
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper	r
Average SA	Equal variances assumed	0.099	0.754	2.887	51.000	0.006	2.246	0.778	0.684	3.808	0.375
	Equal variances not assumed			2.715	31.192	0.011	2.246	0.827	0.559	3.933	

Independent Samples Test between Upper and Lower Body Sports

		Levene's Test for Equality of Variances		t-test for Equality of Means							
									95% Confidence Interval of the Difference		r
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper	
Average SA	Equal variances assumed	0.558	0.458	-2.328	51.000	0.024	-1.808	0.776	-3.366	-0.249	0.310
	Equal variances not assumed			-2.189	34.834	0.035	-1.808	0.826	-3.484	-0.131	

Independent Samples Test between Internal and External Players

		Levene's Test for Equality of Variances		t-test for Equality of Means							
									95% Confidence Interval of the Difference		r
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper	
Average SA	Equal variances assumed	0.006	0.937	-1.497	51.000	0.141	-1.181	0.789	-2.765	0.403	0.205
	Equal variances not assumed			-1.479	46.387	0.146	-1.181	0.798	-2.787	0.426	

ANOVA's

ANOVA

Absolute value of SA

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3.406	2	1.703	0.396	0.675
Within Groups	215.222	50	4.304		
Total	218.628	52			

ANOVA INT/ Ext VS SA

Average Symmetry Angle

			Sum of Squares	Df	Mean Square	F	Sig.	ω2	ω
Between Groups	(Combined)		29.122	2	14.561	1.782	0.179	0.030662055	0.175105838
	Linear Term	Unweighted	10.705	1	10.705	1.310	0.258	ω	
		Weighted	8.316	1	8.316	1.018	0.318	0.563861637	
		Deviation	20.806	1	20.806	2.546	0.117		
Within Groups			408.582	50	8.172				
Total			437.704	52					

ANOVA Between Position on the Field

Average Symmetry Angle

	Sum of Squares	Df	Mean Square	F	Sig.	ω^2	Ω
Between Groups	29.122	2	14.561	1.782	0.179	0.029	0.169
Within Groups	408.582	50	8.172				
Total	437.704	52					

ANOVA Between Sports

Average Symmetry Angle

	Sum of Squares	Df	Mean Square	F	Sig.	ω^2	Ω
Between Groups	87.355	4	21.839	2.992	0.028	7.432	2.726
Within Groups	350.349	48	7.299				
Total	437.704	52					

a. Asymptotically F distributed.

Post-hoc test

Multiple Comparisons

Dependent Variable:

(I) Sport			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tukey HSD	Baseball	Men's Soccer	-2.05193	1.25535	0.483	-5.6098	1.5059
		Softball	1.43824	1.21401	0.760	-2.0025	4.8790
		Women's Soccer	0.44308	1.25535	0.997	-3.1148	4.0010
		Volleyball	1.24007	1.28151	0.868	-2.3919	4.8721
	Men's Soccer	Baseball	2.05193	1.25535	0.483	-1.5059	5.6098
		Softball	3.49018*	1.10680	0.022	0.3533	6.6270
		Women's Soccer	2.49501	1.15199	0.210	-0.7699	5.7599
		Volleyball	3.29200	1.18044	0.056	-0.0536	6.6376
	Softball	Baseball	-1.43824	1.21401	0.760	-4.8790	2.0025
		Men's Soccer	-3.49018*	1.10680	0.022	-6.6270	-0.3533
		Women's Soccer	-0.99517	1.10680	0.896	-4.1320	2.1417
		Volleyball	-0.19818	1.13638	1.000	-3.4189	3.0225
	Women's Soccer	Baseball	-0.44308	1.25535	0.997	-4.0010	3.1148
		Men's Soccer	-2.49501	1.15199	0.210	-5.7599	0.7699
		Softball	0.99517	1.10680	0.896	-2.1417	4.1320
		Volleyball	0.79699	1.18044	0.961	-2.5486	4.1425
	Volleyball	Baseball	-1.24007	1.28151	0.868	-4.8721	2.3919
		Men's Soccer	-3.29200	1.18044	0.056	-6.6376	0.0536
		Softball	0.19818	1.13638	1.000	-3.0225	3.4189
		Women's Soccer	-0.79699	1.18044	0.961	-4.1425	2.5486
Games-Howell	Baseball	Men's Soccer	-2.05193	1.22504	0.479	-5.8910	1.7871
		Softball	1.43824	0.87530	0.490	-1.1978	4.0743
		Women's Soccer	0.44308	0.89535	0.987	-2.2978	3.1839
		Volleyball	1.24007	0.91216	0.661	-1.5858	4.0659
	Men's Soccer	Baseball	2.05193	1.22504	0.479	-1.7871	5.8910
		Softball	3.49018	1.33872	0.112	-0.5685	7.5488
		Women's Soccer	2.49501	1.35191	0.381	-1.6065	6.5965
		Volleyball	3.29200	1.36310	0.158	-0.8458	7.4298
	Softball	Baseball	-1.43824	0.87530	0.490	-4.0743	1.1978
		Men's Soccer	-3.49018	1.33872	0.112	-7.5488	0.5685
		Women's Soccer	-0.99517	1.04552	0.873	-4.1012	2.1109
		Volleyball	-0.19818	1.05995	1.000	-3.3675	2.9712
		Baseball	-0.44308	0.89535	0.987	-3.1839	2.2978

	Women's Soccer	Men's Soccer	-2.49501	1.35191	0.381	-6.5965	1.6065
		Softball	0.99517	1.04552	0.873	-2.1109	4.1012
		Volleyball	0.79699	1.07656	0.944	-2.4424	4.0364
	Volleyball	Baseball	-1.24007	0.91216	0.661	-4.0659	1.5858
		Men's Soccer	-3.29200	1.36310	0.158	-7.4298	0.8458
		Softball	0.19818	1.05995	1.000	-2.9712	3.3675
		Women's Soccer	-0.79699	1.07656	0.944	-4.0364	2.4424
Dunnett t (>control)[b]	Baseball	Volleyball	1.24007	1.28151	0.387	-1.5971	
	Men's Soccer	Volleyball	3.29200*	1.18044	0.013	0.6786	
	Softball	Volleyball	-0.19818	1.13638	0.848	-2.7140	
	Women's Soccer	Volleyball	0.79699	1.18044	0.518	-1.8164	

*. The mean difference is significant at the 0.05 level.

b. Dunnett t-tests treat one group as a control, and compare all other groups against it.

Factorial ANOVA

Factorial ANOVA Between Gender and Sport				F	Sig.	Partial Eta Squared
Corrected Model				2.992	0.028	0.200
Intercept	2.271	1.000	2.271	0.311	0.580	0.006
Sport	25.871	3.000	8.624	1.182	0.327	0.069
Gender	0.000	0.000				0
Sport * Gender	0.000	0.000				0
Error	350.349	48.000	7.299			
Total	444.758	53.000				
Corrected Total	437.704	52.000				

Correlations

Correlations			
		Average Symmetry Angle	Third of the field played (Men & Women)
Average Symmetry Angle	Pearson Correlation	1	0.138
	Sig. (2-tailed)		0.325
	N	53	53
Third of the field played (Men & Women)	Pearson Correlation	0.138	1
	Sig. (2-tailed)	0.325	
	N	53	53

Correlations			
		Average Symmetry Angle	Third of the field played (Men)
Average Symmetry Angle	Pearson Correlation	1	0.226
	Sig. (2-tailed)		0.352
	N	53	19
Third of the field played (Men)	Pearson Correlation	0.226	1
	Sig. (2-tailed)	0.352	
	N	19	19

Correlations			
		Average Symmetry Angle	Third of the field played (Women)
Average Symmetry Angle	Pearson Correlation	1	-0.002
	Sig. (2-tailed)		0.992
	N	53	34
Third of the field played (Female)	Pearson Correlation	-0.002	1
	Sig. (2-tailed)	0.992	
	N	34	34

Regression Analysis

Gender

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.375[a]	0.140	0.124	2.71604
a. Predictors: (Constant), Gender				

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	61.483	1	61.483	8.335	.006[b]
	Residual	376.221	51	7.377		
	Total	437.704	52			
a. Dependent Variable: Average Symmetry Angle						
b. Predictors: (Constant), Gender						

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	3.322	1.330		2.497	0.016
	Gender	-2.246	0.778	-0.375	-2.887	0.006
a. Dependent Variable: Average Symmetry Angle						

Sport

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.253[a]	0.064	0.046	2.83427
a. Predictors: (Constant), Sport				

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.016	1	28.016	3.488	.068[b]
	Residual	409.688	51	8.033		
	Total	437.704	52			
a. Dependent Variable: Average Symmetry Angle						
b. Predictors: (Constant), Sport						

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.317	0.981		1.342	0.185
	Sport	-0.547	0.293	-0.253	-1.868	0.068

Position

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.138[a]	0.019	0.000	2.90162
a. Predictors: (Constant), Position				

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	8.316	1	8.316	0.988	.325[b]
	Residual	429.389	51	8.419		
	Total	437.704	52			
a. Dependent Variable: TA_SA						
b. Predictors: (Constant), Position						

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.489	1.200		-1.241	0.220
	Position	0.579	0.582	0.138	0.994	0.325
a. Dependent Variable: TA_SA						

Gender and Sport

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.392[a]	0.154	0.120	2.72175
a. Predictors: (Constant), Gender, Sport				

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	67.309	2	33.654	4.543	.015[b]
	Residual	370.395	50	7.408		
	Total	437.704	52			
a. Dependent Variable: Average Symmetry Angle						
b. Predictors: (Constant), Gender, Sport						

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	3.670	1.390		2.641	0.011
	Sport	0.461	0.520	0.213	0.887	0.379
	Gender	-3.322	1.443	-0.554	-2.303	0.025

a. Dependent Variable: Average Symmetry Angle

Sport Rearranged

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	77.015	1	77.015	10.890	.002[b]
	Residual	360.689	51	7.072		
	Total	437.704	52			

a. Dependent Variable: Average Symmetry Angle

b. Predictors: (Constant), New sport

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-2.745	0.808		-3.395	0.001
	New sport	0.824	0.250	0.419	3.300	0.002

a. Dependent Variable: Average Symmetry Angle

Raw SA Data

Baseball				
Subjects	Average Symmetry Angle			
	Trial 1	Trial 2	Trial 3	Average SA
BB0154	-1.86	-2.72	-1.32	-1.96
BB0233	-4.69	-1.34	1.83	-1.4
BB0348	3.33	-3.89	1.59	0.32
BB0450	2.16	2.28	1.92	2.12
BB0544	-2.78	1.40	-1.09	-0.78
BB0618	4.19	-0.51	-0.49	1.07
BB0707	3.05	0.86	-1.93	0.64
BB0838				
BB0814				
BB1055	0.31	-0.22	-2.70	-0.90

Men's Soccer				
Subjects	Average Symmetry Angle			
	Trial 1	Trial 2	Trial 3	Average SA
MS0108	-2.77	-1.91	-0.63	-1.74
MS0216	-4.00	-0.12	-0.22	-1.45
MS0312	-0.11	-1.02	-2.11	-1.09
MS0453	0.25	1.07	-1.43	-0.07
MS0527	-0.75	-0.18	1.01	0.03
MS0610	-0.61	1.80	-0.61	0.15
MS0736	1.88	-0.70	2.44	1.19
MS0843	4.97	4.55	1.57	3.70
MS0915	3.63	6.60	1.01	3.75
MS1037	5.10	7.28	9.55	7.26

Softball				
Subjects	**Average Symmetry Angle**			
	Trial 1	**Trial 2**	**Trial 3**	**Average SA**
SB0103	-5.63	-0.14	-9.89	-5.19
SB0204	-5.63	-0.14	-9.89	-5.19
SB0309	-6.95	-1.15	-6.05	-4.68
SB0447	-6.43	-5.07	-2.05	-4.50
SB0551	-5.61	-3.27	-0.17	-2.84
SB0630	-1.71	-0.24	-1.58	-1.20
SB0725	-0.98	-0.05	-0.69	-0.57
SB0849	-1.66	-0.65	1.08	-0.40
SB0911	-0.46	-0.51	-0.23	-0.40
SB1052	-1.81	2.57	0.28	0.36

Volleyball				
Subjects	**Average Symmetry Angle**			
	Trial 1	**Trial 2**	**Trial 3**	**Average SA**
VB0146	-4.21	-7.97	-1.15	-4.47
VB0222	0.30	-4.13	-6.86	-3.6
VB0320	-4.26	-2.93	-3.60	-3.59
VB0423	-3.46	-2.66	-3.19	-3.11
VB0519	-2.15	-0.24	-3.34	-1.90
VB0605	0.59	-2.67	-0.52	-0.92
VB0724	4.80	-2.71	-2.85	-0.17
VB0802	3.60	0.04	-3.82	-0.09
VB0929	2.00	1.25	-0.02	1.06
VB1035	6.63	1.59	2.03	3.27

Women's Soccer				
Subjects	**Average Symmetry Angle**			
	Trial 1	**Trial 2**	**Trial 3**	**Average SA**
WS0106	-5.36	-5.05	-7.28	-5.91
WS0228	-8.07	-4.31	-0.31	-4.26
WS0301	-1.46	0.24	-2.90	-1.34
WS0417	-0.87	-2.61	2.15	-0.44
WS0542	-0.12	-0.67	0.09	-0.23
WS0645	0.57	-1.65	1.57	0.17
WS0739	-1.33	0.47	1.76	0.29
WS0813	0.81	1.61	-0.01	0.82
WS0931	1.83	-0.74	1.41	0.87
WS1041	3.19	0.13	0.30	1.23
WS1132	3.97	0.74	3.18	2.70