

Spring 5-11-2017

The Relationship of Anthropometric Ratios and Kinematic & Kinetic Measures of the Hip in Recreational Male Athletes Performing the Back Squat

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of the Hip in Recreational Male Athletes Performing the Back Squat**

By

Jay C. Garrels

Dissertation Committee

Dr. Richard Boergers, Chair

Dr. Jim Phillips

Dr. Fortunato Battaglia

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Health Sciences

Seton Hall University

2017

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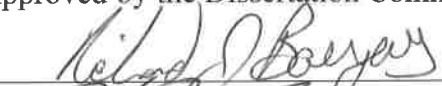


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	Date	4-18-17
	Date	4/18/17
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ABSTRACT

The back squat exercise is a popular resistance exercise that involves synchronous movement of the entire body to perform the movement properly. The two main focuses when considering engaging in the back squat exercise are the risks of injury and the enhancement of performance. There is little information and scant understanding on the way body proportionality impacts the risk of injury and performance. The present study investigated this issue by investigating if there was a relationship between anthropometric ratios and kinematic & kinetic outcomes from the left and right hip when experienced, male back squatters performed a single repetition at 80% of 1RM load. Additionally, this study compared the kinematic & kinetic outcomes of the left and right hip.

The results of this study showed that amongst experienced, male back squatters, there was no relationship of kinematic and kinetic outcomes to the anthropometric ratios. The results did indicate that there were significant differences between the outcomes of the left and right hip in four of the twelve comparisons.

There was little variance amongst the anthropometric ratios of the subjects and they were an experienced group of back squatters. These two factors are believed to have impacted the results. Future studies could use subjects of more varied anthropometric ratios and subjects with less experience.

ACKNOWLEDGEMENTS

The doctoral journey is not one that can be done alone. I am so appreciative of the love and support that I received from my family and friends to help me get through a very rigorous process and achieve my goals. To my wife Ali, you stood by me from day one and gave me the encouragement I needed to persevere; I could not have completed this dissertation without you by my side. To my mom, Ru, and Ted- your sacrifice and willingness to care for Abraham and Nathan when my focus needed to be on my dissertation work is something I will always be indebted to you for. Dr. Boergers- I just want to say thank you! Thank you for selflessly giving your all into my research. The multiple hour long conversations we had forced me to produce the best possible product that I could. You have made me a better scholar because you challenged me to think and you would not let me settle. You pushed me and I came out on the other side a better academic. Dr. Phillips- you guided me from the beginning and you helped me stay grounded and focused; thank you for your help to get me over the finish line. Dr. Battaglia- thank you for your contributions to the research, you made me think critically and come to conclusions that helped me to focus the results of the research.

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Chapter I

INTRODUCTION

Injury prevention and performance enhancement are two of the major benefits elite athletes reap from participation in resistance training (Shoenfeld, 2010). Many resistance training programs focusing on improvements in the lower extremities utilize the back squat exercise for injury prevention, overall strength improvement, and performance enhancement (Gorsuch, Long, Primeau, Rutledge, Sossong, & Durocher, 2010; & Schoenfeld, 2010). The hip region is an important anatomical location for the squat exercise because this region works in an eccentric manner to control the descent of the body and external load and concentrically during the ascent during the back squat (Floyd, 2015; Hall, 2015; & Schoenfeld, 2010). Excessive force, asymmetry between the left and right hip complex, and any hip dysfunction may lead to an increased risk of injury and inhibit performance enhancement. Causation of these factors is not completely understood and that puts athletes and squat performers at risk of injury and may impede the enhancement of their performance (Floyd, 2015; Caruso, McLagan, Shepherd, Olson, Taylor, Gillibrand, Kline, Detwiler, and Griswold, 2009; & Schoenfeld, 2010). Despite the high volume of research conducted on the squat exercise, there is a limited amount of investigation on the impact of body type proportionality on outcomes from the back squat. During the extensive review of the research that was located for this study, anthropometric factors, such as limb length, were not factored into analysis in a comparative way.

Some studies did record anthropometric measurements, but they did so for data collection purposes or required for subject parameters for motion analysis (Butler, Plisky, Southers, Scoma, & Kiesel, 2010; Cortes, Greska, Kollock, & Onate, 2011; Delmore, Laudner, Torry, 2014; Fauth, Garceau, Lutsch, Gray, Szalkowski, Wurm, & Ebben, 2010; & Gullett, Tillman, Gutierrez, & Chow, 2009). The intent of this study is to explore this gap in the research by evaluating if anthropometric measures impact squat outcomes.

The squat is a popular exercise for assessing overall strength of the musculoskeletal system, especially in the lower back and lower extremities (Butler et al, 2010; & Gorsuch et al, 2010). The back squat is used for evaluation purposes and this assessment could be an indicator of overall health or training status, depending on the population (Fahey, 2015). The National Strength and Conditioning Association (NSCA), an accredited governing body in the resistance training field, outlines specific guidelines on how to appropriately perform the squat exercise, and states further, that when included into a training program, injuries risk will be reduced and performance will be enhanced (Butler et al, 2010; Delmore et al, 2014; Gorsuch et al, 2010; & Strutzenberger, Simonidis, Krafft, Mayer, & Schwameder, 2010). The squat exercise is also used for evaluative and training purposes (Butler et al, 2010; Schoenfeld, B, 2010).

This exercise is a very common and popular exercise. Due to its prevalence in performance settings, the back squat warrants extensive research on every component that can impact outcomes. The interpretation of these outcomes can lend to researcher's understanding on injury and performance implications on the muscles, joints, and other musculoskeletal components. The investigation into body proportionality through understanding the contributions, or absence of contributions, of anthropometrics is crucial to keeping squat performers injury free and able to perform at their peak ability.

The back squat exercise provides many benefits, but it has also been found to have a high risk of complaint (List, Gulay, & Lorenzetti, 2010). It is due to this conundrum that questions arise about the appropriateness of having all athletes perform the back squat. This issue is not being addressed because it is unknown if there is a need or not. For example, the evaluation of anthropometric measures through a screening tool is not a part of the process for deciding the appropriateness of participation in the back squat for athletes because it is unknown if there is a relationship between anthropometrics and back squat outcomes (Baechle & Earle, 2008). At this point, these factors are not considered when it comes to including the back squat in an exercise plan or excluding it.

The research that was identified for this study showed that anthropometrics were not a consideration for determining if a back squat should be utilized in a training protocol for an individual squatter. For example, a study by Augustsson,

Augustsson, Thomeé, Karlsson, Eriksson, & Svantesson, (2011) found that significant improvements were made in performance by incorporating the squat exercise. The study was a 26 week long intervention program for performance enhancement amongst female volleyball players. The design called for a control group and an experimental group with the experimental group receiving supervision and instruction, but every performer did the same lifts. They were all doing the same exercises in the same manner, regardless of any anthropometric differences.

(Augustsson et al, 2011) Many studies that were reviewed for this present study showed a similar trend where some anthropometric data was collected, but was not analyzed in any meaningful way. Due to this circumstance, it is unknown if these participants' results were significantly different due to their anthropometric ratios.

The squat is one of the most beneficial exercises for the development of the lower extremities (and ultimately, the entire body) because it utilizes the major muscle groups of the lower extremities in an agonist manner and as well as many muscles in the upper body in a synergistic fashion (Floyd, 2015; Gorsuch et al, 2010; Hall, 2015; Robertson, Wilson, St. Pierre, 2008; & Han, Ge, Liu, & Liu, 2013). At the same time, it is one of the more dynamic and complex resistance exercises because it incorporates multiple muscle groups and multiple joints. Balance, range of motion, and flexibility are important characteristics in performing the exercise correctly (Madhavan, Burkart, Baggett, Nelson, Teckenburg, Zwanziger, & Shields, 2009).

Due to its complex nature, proper technique is critical to staying injury free (Butler et al, 2010; Dionisio, Almeida, Duarte, & Hirata, 2008; & Schoenfeld, 2010). It is not fully understood, however, why some performers have better outcomes and less complaint than others; the present study investigated if anthropometric ratios of body proportionality had a relationship to kinematic and kinetic outcomes in the squat exercise to see if more reasoning could be added to why different results were being found.

The spine, hip, knee, and ankle are the primary anatomical complexes involved with the squat exercise (Butler et al, 2010; Han et al, 2013; List, et al, 2010; Robertson et al, 2008; Schoenfeld, 2010; & Sinclair et al, 2014). It is through these complexes that the proper execution of the back squat exercise occurs. Proper time sequencing is vital to completing the exercise as outlined by the NSCA. To understand the complexity of the squat maneuver, the following is list of the instructions for the back squat: The squat exercise calls for the athlete to start in the upright position with their feet parallel and just a little further than shoulder width apart. The athlete then performs simultaneous hip and knee flexion while maintaining a strong torso to floor angle that is approximately upright. The heels remain on the floor and knees stay aligned over the feet. This downward phase continues until the thighs are parallel to the floor. Once that point is reached, the athlete performs simultaneous hip and knee extension until they return to the starting position.

The participant is instructed to maintain a constant trunk to floor angle (limited forward lean) and keep a flat back and erect spine (Shoenfeld, 2010). These are the instructions for the body weight squat and these instructions hold true when modifications are made to the exercise (Baechle & Earle, 2008). Once such modification is the addition of load to the exercise. Two common modifications for the squat are the back squat and the front squat. Researchers indicate that the squat is typically performed with a universal bar weighing approximately 20 kilograms with the ability to add weight if so desired. The placement of the bar is the defining factor when discerning the difference between the back squat and the front squat. For the back squat, the bar is placed in either a high bar position or a low bar position. The high bar position is above the posterior deltoids at the base of the neck. The low bar position for the back squat places the midpoint of the bar at the spine across posterior deltoids at the middle of the trapezius. (Baechle & Earle, 2008) Despite the benefits of the squat exercise, both unloaded or modified with a load, it must be recognized that the squat exercise is a very technical exercise and adherence to all the instructions of the squat is a concern because if an individual is unable to perform correctly, non-compliance can lead to injury (Baechle & Earle, 2008; Han et al, 2013; Robertson et al, 2008, & Schoenfeld, 2010).

Adherence to exercise programs is a common issue found when assessing injury prevention and performance enhancement. Participant characteristics and

previous experiences impact adherence to exercise protocols (Anton et al., 2005). This is important because it further adds to the need of assessing each athlete, and prescribing for each athlete on an individual basis. Included in exercise programming is a needs analysis, which is an evaluation facilitated by a strength and conditioning professional that occurs prior to exercise and should act as an identifier for potential barriers and injuries related to the specific athlete being assessed. Using a screening tool can help assess the risk of injury to the lower extremities and thus aid in increasing adherence for the athlete (Dallinga, Benjaminse, & Leinmink, 2012). Even with the implementation of these procedures, there is no guarantee that the participant will follow all instructions and will not be at a higher risk of injury. At this time, anthropometric measures are not a part of the assessment tool prior to prescribing the squat exercise for elite athletes.

Investigations into other variations on the squat are important to understanding the outcomes of the back squat. For example, understanding the biomechanical differences between the back and front squat can help researchers identify unique differentiators in each exercise and commonalities (Gullett et al, 2009). This furthers the understanding of the outcomes from these exercises and can potentially address some of the issues presented in this paper. For example, the front squat is performed much in the same manner as the unloaded squat, however, this loaded squat places a load of weight just under the chin of the athlete, instead of posteriorly as seen in the back squat. The front squat is used to develop leg strength,

same as in the back squat, however, the compressive forces and extensor moments in the knee are less in the front squat compared to the back squat (Gullett et al, 2009; Waller & Townsend, 2007). The draw back to the placement of load anteriorly is that it may make performing the front squat exercise correctly much more challenging than the back squat, if the loads are the same in both instances. In the Gullett et al (2009) study, a 70% one repetition maximum was used and the average back squat was approximately thirteen kilograms greater than the front squat. When considering the 1RM loads at 70% of the squat variations, it is important to recognize that varying anthropometric measures could have an impact on these outcomes.

The squat exercise requires balance during the movement to perform the exercise correctly and prevent injury (Madhavan et al, 2009). The center of mass is a theoretical point where the body's mass is to be equally distributed, and within balanced subject the center of mass will be located within its base of support. This location changes with alterations to the body's position and has an impact on the likelihood toppling will occur (Chapman, 2008). The presence of inertia (meaning, the body will continue a movement) is counteracted by forces generated by the muscles in the lower extremities (gluteus maximus, semimembranosus, semitendinosus, biceps femoris, vastus lateralis, vastus intermedius, and rectus femoris) during the squat (Baechle & Earle, 2008; Chapman, 2008). Knowing the importance of displacement of the center of mass during the back squat renders an important question about the impact of varying limb lengths on outcomes of the

exercise, specifically, kinematic and kinetic measures. This critical element of displacement of center of mass during the squat merits an evaluation of how the squat is prescribed and the impact it potentially could have on our understanding of the squat (Chapman, 2008).

Kellis et al (2005) conducted a study on 8 male university physical education students that were 22.1 +/- .8 years, 1.78 +/- .06 m, and 75.8 +/- 7.9 kgs. All subjects were healthy. The researchers examined the effects of external load during squats of vertical ground reaction forces, and linear and angular kinematics. Maximal concentric squats were performed at different loads ranging from 7 to 70% of 1 maximal repetition. The data was recorded from force plates and video camera for motion analysis. The results from this study indicated maximal force exertion was not achieved at the same position as load increased. This study did find, however, that the force-velocity was linear and joint velocity coordination did not change as load increased. (Kellis et al, 2005)

There is other research present that trends along this notion of change in positioning based on load. In an article by McBride, Haines, and Kirby (2011), the researchers used nine males to evaluate performance of squat ranging in load ranges from 30% to 90% of one maximal repetition. Results from this study indicated that the amount of load affected kinematic movement patterns. These researchers found that peak power outputs were different at every testing interval (McBride et al, 2011). Changes in kinematics will impact kinetic results because the kinetic results are

derived through inverse dynamics, which use kinematics to determine the force results (Hall, 2015). Cormie, McBride, and McCaulley (2007) investigated the validity of power measurement in kinematic and kinetic data in the squat. These researchers found that the load-power relationship of dynamic lower body movements in kinematic and kinetic data were different at different intensities. These study used 10 division 1 male athletes for their study. The influence of load during the squat exercise significantly impacted kinematic and kinetic outcomes (Kellis et al, 2005; McBride et al, 2011; & Cormie et al, 2007). These researchers did not indicate in their publications if the range of displacement due to anthropometric segment lengths could have been a contributing factor on the impact that was found in kinematic and kinetic outcomes.

Proper technique while executing the back squat is crucial to avoiding injury to the lower back region (Baechle & Earle, 2008; & Schoenfeld, 2010). Forward lean and forward bending, particularly during weight lifting, is not recommended because a significant increase in pressure is found as compared to a straight back (or as upright as possible while maintaining a constant torso to floor angle), which is what is recommended. Although causation of injuries is difficult to quantify, it is believed that improper technique increases the risk of injury (Chandler & Stone, 1991). It is understood that different positions and varying loads impact the amount of pressure in the spine. For example, it was found that lifting a 20 kg weight bent over with a round back (improper form) caused approximately 35% more pressure in the center of

the L4-L5 nucleus pulposus (measured with an implanted transducer) than lifting the same load using the proper technique in back squat. It was also found that the lifting movement caused greater pressure than any other position or exercise, such as lying supine to walking/jogging, & climbing stairs (Nachemson & Elfstrom, 1970; Wilke, Neef, Caimi, Hoogland, & Claes, 1999). Despite not knowing the impact of anthropometric ratios on lifting exercises, such as the back squat, it is important to recognize the significantly greater force generated during such exercises compared to other positions and exercises (Floyd, 2015; Gullett et al, 2009; & Hall, 2015). This is important because greater forces may increase the risk of injury (Hall, 2015).

Purpose:

The purpose of the present study is to explore if a correlation exists between a subject's anthropometric ratios (hip width/height & torso length/height) and their back squat performance evaluated by kinematic (joint angles) and kinetic outcomes (joint moments, powers, forces) in the left and right hip.

Research Questions

RQ1. Is there a correlation between the *anthropometric ratios* and *kinematic & kinetic outcomes* in the left hip (a) in the three planes (X, Y, & Z) of motion when performing the back squat?

RQ2. Is there a correlation between the *anthropometric ratios* and *kinematic & kinetic outcomes* in the right hip (b) in the three planes (X, Y, & Z) of motion when performing the back squat?

RQ3. Is there a difference between the *kinematic & kinetic outcomes* between the left & right hip in the three planes (X, Y, & Z) of motion when performing the back squat?

Hypotheses

Hip Width to Height Ratio and Outcomes of the Left Hip in the Sagittal Plane

H1iXa- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the left hip in the sagittal plane.

H1iiXa- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the sagittal plane.

H1iiiXa- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the sagittal plane.

H1ivXa- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the sagittal plane.

Hip Width to Height Ratio and Outcomes of the Left Hip in the Frontal Plane

H1iYa- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the left hip in the frontal plane.

H1iiYa- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the frontal plane.

H1iiiYa- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the frontal plane.

H1ivYa- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the frontal plane.

Hip Width to Height Ratio and Outcomes of the Left Hip in the Transverse

Plane

H1iZa- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the left hip in the transverse plane.

H1iiZa- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the transverse plane.

H1iiiZa- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the transverse plane.

H1ivZa- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the transverse plane.

Hip Width to Height Ratio and Outcomes of the Right Hip in the Sagittal Plane

H1iXb- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the right hip in the sagittal plane.

H1iiXb- There will be a relationship between hip width to height ratio and the moment (Nm) in the right hip in the sagittal plane.

H1iiiXb- There will be a relationship between the hip width to height ratio and the power (Watts) output in the right hip in the sagittal plane.

H1ivXb- There will be a relationship between the hip width to height ratio and the force (N) in the right hip in the sagittal plane.

Hip Width to Height Ratio and Outcomes of the Right Hip in the Frontal Plane

H1iYb- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the right hip in the frontal plane.

H1iiYb- There will be a relationship between hip width to height ratio and the moment (Nm) in the right hip in the frontal plane.

H1iiiYb- There will be a relationship between the hip width to height ratio and the power (Watts) output in the right hip in the frontal plane.

H1ivYb- There will be a relationship between the hip width to height ratio and the force (N) in the right hip in the frontal plane.

Hip Width to Height Ratio and Outcomes of the Right Hip in the Transverse Plane

H1iZb- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the right hip in the transverse plane.

H1iiZb- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the transverse plane.

H1iiiZb- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the transverse plane.

H1ivZb- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the transverse plane.

Torso Length to Height Ratio and Outcomes of the Left Hip in the Sagittal Plane

H2iXa- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the left hip in the sagittal plane.

H2iiXa- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the sagittal plane.

H2iiiXa- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the sagittal plane.

H2ivXa- There will be a relationship between the torso length to height and the force (N) in the left hip in the sagittal plane.

Torso Length to Height Ratio and Outcomes of the Left Hip in the Frontal Plane

H2iYa- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the left hip in the frontal plane.

H2iiYa- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the frontal plane.

H2iiiYa- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the frontal plane.

H2ivYa- There will be a relationship between the torso length to height ratio and the force (N) in the left hip in the frontal plane.

Torso Length to Height Ratio and Outcomes of the Left Hip in the Transverse Plane

H2iZa- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the left hip in the transverse plane.

H2iiZa- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the transverse plane.

H2iiiZa- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the transverse plane.

H2ivZa- There will be a relationship between the torso length to height ratio and the force (N) in the left hip in the transverse plane.

Torso Length to Height Ratio and Outcomes of the Right Hip in the Sagittal Plane

H2iXb- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the right hip in the sagittal plane.

H2iiXb- There will be a relationship between the torso length to height ratio and the moment (Nm) in the right hip in the sagittal plane.

H2iiiXb- There will be a relationship between the torso length to height ratio and the power (Watts) output in the right hip in the sagittal plane.

H2ivXb- There will be a relationship between the torso length to height ratio and the force (N) in the right hip in the sagittal plane.

Torso Length to Height Ratio and Outcomes of the Right Hip in the Frontal Plane

H2iYb- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the right hip in the frontal plane.

H2iiYb- There will be a relationship between the torso length to height ratio and the moment (Nm) in the right hip in the frontal plane.

H2iiiYb- There will be a relationship between the torso length to height ratio and the power (Watts) output in the right hip in the frontal plane.

H2ivYb- There will be a relationship between the torso length to height ratio and the force (N) in the right hip in the frontal plane.

Torso Length to Height Ratio and Outcomes of the Right Hip in the Transverse Plane

H2iZb- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the right hip in the transverse plane.

H2iiZb- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the transverse plane.

H2iiiZb- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the transverse plane.

H2ivZb- There will be a relationship between the torso length to height ratio and the force (N) in the left hip in the transverse plane.

Differences between Left and Right Hip Outcomes in the Sagittal Plane

H3iX- There will be no difference in the i. angle measurements outcomes between the left and right hip in the sagittal plane.

H3iiX- There will be no difference in the ii. moment outcomes between the left and right hip in the sagittal plane.

H3iiiX- There will be no difference in the iii. power outcomes between the left and right hip in the sagittal plane.

H3ivX- There will be no difference in the iv. force outcomes between the left and right hip in the sagittal plane.

Differences between Left and Right Hip Outcomes in the Frontal Plane

H3iY- There will be no difference in the i. angle measurements outcomes between the left and right hip in the frontal plane.

H3iiY- There will be no difference in the ii. moment outcomes between the left and right hip in the frontal plane.

H3iiiY- There will be no difference in the iii. power outcomes between the left and right hip in the frontal plane.

H3ivY- There will be no difference in the iv. force outcomes between the left and right hip in the frontal plane.

Differences between Left and Right Hip Outcomes in the Transverse Plane

H3iZ- There will be no difference in the i. angle measurements outcomes between the left and right hip in the transverse plane.

H3iiZ- There will be no difference in the ii. moment outcomes between the left and right hip in the transverse plane.

H3iiiZ- There will be no difference in the iii. power outcomes between the left and right hip in the transverse plane.

H3ivX- There will be no difference in the iv. force outcomes between the left and right hip in the transverse plane.

Operational Definitions

For the present study, the following definitions were applied:

1. The back squat exercise will follow the guidelines set forth by the National Strength and Conditioning Association (NSCA).
2. Each participant will follow the same procedure to determine percentages of 1 RM (repetition max). The method for establishing 1 RM will follow the procedure set forth by the NSCA.
3. Kinematic performance is defined by the range of motion, in degrees, of the thighs in relation to the hips. Kinetic performance is defined by the joint force, moments, and power generated in the hip complex.
4. Anthropometric ratios will be defined by segment lengths to overall height in both the vertical and horizontal axes. For the horizontal ratio, the distance from the Left & Right Anterior Superior Iliac Spines (ASIS) were measured and divided into overall height defined as top of the head to base of the heel. The vertical ratio was established by measuring from the acromioclavicular joint to the ASIS and divided into the overall height.

Theoretical Framework

The theoretical framework for this study falls under the Theoretical Model of Strength Training, which was written to capture the appropriate design and modeling for resistance training activities. The outline set forth in the model explains the traditional phases of program design, which are hypertrophy, basic strength, strength-power, and peaking maintenance. The model further states the importance of planning each training session to gain the most benefit from participation in the prescribed activities, especially when it comes to short term and long term adaptations. Additionally, the model provides insight into the potential adverse outcomes from not following a planned training program. The gap in this theoretical frame is that not all impactful components of resistance training are accounted for, such as anthropometric measurements and associated ratios (Stone, O'Bryant, Garhammer, McMillan, & Rozenek, 1982).

Summary

The goal of strength and conditioning specialists is two-fold: decrease risk of injury and improve performance. Resistance training is a valuable resource for these specialists to be most effective in executing their jobs as they attempt to achieve their goals. Putting into place best practices is part of the evolution of the application of knowledge in the field of strength training. The knowledge that directs the procedures used in the field comes from research, such as the research presented in this study. The impact of anthropometric measurements and ratios has been scarcely

researched and warrants further exploration as it relates to the appropriate exercise prescription of the back squat exercise.

Chapter II

Literature Review

Kinematics & Kinetics

The squat exercise is performed by individuals utilizing all three joints of the lower extremities (hip, knee, & ankle). The hip joint is a ball and socket joint that freely moves in all three planes of movement (sagittal, frontal, and transverse) (Delmore et al, 2014; Floyd, 2015; Hall, 2015; Han et al, 2013; & Shoenfeld, 2010). Flexion and extension of the hip joint occur in the sagittal plane, abduction and adduction occur in the frontal plane, and internal and external rotation occur in the transverse plane (Baechle & Earle, 2008; Shoenfeld, 2010). The full range of motion that the hip joint has is important to understand because it means that while performing the squat exercise, it is possible that the hip could perform movements not outlined by the exercise prescription, which, in theory, would increase the risk of injury (Brandon, Howatson, & Hunter, 2011; Fauth, et al, 2010). Han et al (2013) found in their research that differences in lifestyle, sport requirements, and gender impacted squat performance. For example, when compared to males, females showed more hip adduction and knee valgus when performing the squat (Han et al, 2013). Variations in hip and foot position impact load at the knee, and speculatively, could lead to joint pathologies that lead to injuries (Han et al, 2013; Shoenfeld, 2010). This acknowledgement of differences is important because it lends to the possibility of other impacts, like anthropometric measures, on squat performance.

Joint complexes

When evaluating the hip, knee, and ankle joints during the squat movement, similarities and contrasts in performance have been found. For example, peak angular velocities across the three joints occur simultaneously (Han et al, 2013; & Robertson et al, 2008). The hip and ankle joint share some common traits, such as extensor moments throughout the downward and upward phases of the exercise; while the knee began and ended with a flexor moment and had an extensor moment during the actual movement in between starting and stopping (Robertson et al, 2008; & Shoenfeld, 2010). Also, the hip and ankle demonstrated a similar joint power output pattern where the downward movement phase of the squat elicited an eccentric response and concentric during the upward movement (Butler et al, 2010; Robertson et al, 2008; & Shoenfeld, 2010). The knee, conversely, starts its joint power pattern concentrically, then transition to an eccentric phase for the rest of the descent (Robertson et al, 2008). The switch to the ascent phase of the squat finds that the knee extensors start with concentric contractions and end eccentrically (Robertson et al, 2008). The moments of force follow a similar pattern where the hip and ankle follow a similar pattern with the knee results varying (Butler et al, 2010; Robertson et al, 2008; & Shoenfeld, 2010). The hip and ankle force outputs show that during the downward phase, the moments of force were used to control the downward

movement, where the upward phase found the generation of work about these joints by extensor moments (Han et al, 2013, & Robertson et al, 2008).

The moments of joint forces related to the knee is more complex (Robertson et al, 2008). The knee has four phases, two during the downward movement and two during the upward movement (Han et al, 2013; & Robertson et al, 2008). The initial phase is during the descent where the knee shows positive work then transitions to the second phase of the downward movement where force is dissipated to control the flexion of the knee. The transition into the third phase, which is the upward movement, is the generation of work. Finally, the knee acts eccentrically toward the end of the upward movement to constitute the fourth and final phase. (Robertson et al, 2008)

The movement, and the control of the movement, in the hip area is vital to performing the squat properly (Butler et al, 2010; Han et al, 2013; Robertson et al, 2008; & Shoenfeld, 2010). During the downward movement of the hips, during the squat, hip flexion and hip torque increases, where maximal hip torque is achieved at the lowest position of the movement (Robertson et al, 2008; Shoenfeld, 2010). Trunk stability plays an important role to limiting the amount forward lean occurs during the movement; the less trunk stability, the more forward lean, the increase in unwanted torque, increase risk to injury (List et al, 2010; Shoenfeld, 2010). The hip region

plays the intermediary between the upper and lower extremities and because of this relationship act as a stabilizer for the upper extremity when the lower extremity is in motion, such as during the squat movement (List et al, 2010; & Shoenfeld, 2010).

Muscles

The primary muscles contributing to muscle action and movements in the hip are the gluteus maximus and the hamstring muscle group (semitendinosus, semimembranosus, and biceps femoris) (Baechle & Earle, 2008; & Shoenfeld, 2010). In order to control the squat movement, the gluteus maximus acts eccentrically during the downward movement of the squat and concentrically on the upward movement (Shoenfeld, 2010). The gluteus maximus also stabilizes the pelvis and knee because it is attached ilioband (Shoenfeld, 2010). The level of activation for the gluteus maximus is impacted by the depth of the squat, especially when a full squat is being performed (Gorsuch et al, 2010; Schoenfeld, 2010). The other important muscles that influence the role the hip plays during the squat are the hamstrings. The muscular activity of the hamstrings is not as impactful during the squat as compared to other exercises such as the leg curl. This, however, should be expected because the hamstring is isolated as the dominate muscle involved in that exercise, where the hamstrings are playing a contributing role during the squat. Also, the hamstrings play a dual role in the squat. The hamstrings act as both hip extensors and knee flexors. Another contrast of the hamstrings is that the hamstrings located laterally

produce greater activity than the medial hamstrings. (Schoenfeld, 2010) Squatting impacts the hips, pelvic girdle, and spine in the midsection of the human body, and it is recommended that for proper squat technique to be used, increased hip flexibility and mobility are crucial; where poor mobility in the hips can lead to unwanted forward lean (Delmore et al, 2014; Han et al, 2013; List et al, 2010; Schoenfeld, 2010; & Sinclair et al, 2014)

The knee joint flexes and extends throughout the sagittal plane during the squat exercise (Baechle & Earle, 2008; Schoenfeld, 2010; & Sinclair et al, 2014). Researchers have found small amounts of axial rotation in the knee during squat exercise, and this is because knee joint, also known as the tibiofemoral joint, is a modified hinge joint that is not rigidly confined to the sagittal plane (Schoenfeld, 2010; Sinclair et al, 2014). This rotation allows a shift in the center of rotation at the knee during the squat (Chapman, 2008; Schoenfeld, 2010; & Sinclair et al, 2014). A critical component that provides mechanical leverage during extension of the knee is the patellofemoral joint (Chapman, 2008; Schoenfeld, 2010). This joint glides over the trochlear surfaces to create a greater force arm (Chapman 2008; Schoenfeld, 2010). The knee is a complex anatomical structure that is supported by ligaments and cartilage (Baechle & Earle, 2008; Sinclair et al, 2014). The anterior cruciate ligament (ACL) is popularly known due to a high rate of injury of the ACL, but does have an important role in the knee and that is as a stabilizer (Schoenfeld, 2010). Anterior

translation of the tibia is prevented by the ACL (Schoenfeld, 2010; Sinclair et al, 2014). There is also a posterior cruciate ligament, which acts to prevent posterior tibial translation. Working in the frontal plane are the lateral and medial collateral ligaments to support the knee in varus and valgus moments. These ligaments, along with the cartilage in the knee provide the knee support, especially during stressful activity, such as the squat (Schoenfeld, 2010).

The quadriceps muscles, which are the vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris, are the primary movers of the knee during the squat (Baechle & Earle, 2008; Schoenfeld, 2010; Sinclair et al, 2014). The quadriceps are responsible for concentric knee extension and eccentric knee flexion (Baechle & Earle, 2008; Han et al, 2013; Schoenfeld, 2010). The hamstrings act in a synergistic role that contract in concert with the quadriceps (Han et al, 2013; Schoenfeld, 2010; & Sinclair, 2014). This synergistic relationship is critical to providing adequate support at the knee joint during the squat by reducing stress on the ACL. This is accomplished by a counter pull on the tibia by the hamstrings. Compression at the tibiofemoral and patellofemoral positions is shown to increase with increase in knee angle. (Schoenfeld, 2010) This is important because it further connects the importance of the synergistic role of the hamstrings to counteract the shear generated by the quadriceps. Knee position during the squat is important for the anatomical system to be able to handle the shear forces generated at the knee during flexion and extension. Forward positioning of the knees increases the shear forces generated

during the squat (Han et al, 2013; Schoenfeld, 2010; & Sinclair, 2014). That is why is important to maintain torso to floor angle in order to keep the center of mass over the feet and maintain proper knee movement throughout the sagittal plane (Baechle & Earle, 2008).

The main muscular force generated at the knee are by the quadriceps (Han et al, 2013; Robertson et al, 2008; & Schoenfeld, 2010, & Sinclair, 2014). Peak muscular activity in the quadriceps occurs between 80 to 90 degrees of flexion (Brandon et al, 2011; Butler et al, 2010; Sinclair et al, 2014), although Schoenfeld (2010) contends that the upper range is 90 degrees so going past that point does not gain enhancements in the quadriceps, which impacts those training protocols that call for a full or deep squat to go past the 90 degree threshold. Vastus lateralis and vastus medialis generate approximately the same force output during the squat. However, the vasti muscles of the quadriceps compared to the rectus femoris show a significant difference; vasti produces approximately 50% more muscular output. This is because the rectus femoris is both a hip extensor and knee flexor, so while one is lengthening the other is shortening with little net lengthening change, hence less force production. (Schoenfeld, 2010) It is recommended that the knee refrain from moving in front of the toes during the squat exercise (Butler et al, 2010; Han et al, 2013; Robertson et al, 2008; Schoenfeld, 2010; & Sinclair et al, 2014). Researchers have found that shear forces increase during the descent phase of the squat, and keeping the knee from

translating forward limits those forces. (Butler et al, 2010; Han et al, 2013; Robertson et al, 2008; Schoenfeld, 2010; Sinclair et al, 2014, & Strutzenberger et al, 2010)

The ankle joint is another complex anatomical structure that is made up of the talocrural and subtalar joints (Baechle & Earle, 2008; Schoenfeld, 2010). These two joints work together to allow the ankle joint to perform dorsiflexion, plantarflexion, eversion, and inversion (Baechle & Earle, 2008; Butler et al, 2010; & Schoenfeld, 2010). Additionally, small amounts of abduction and adduction movement have been detected in the ankle joint. During the squat exercise, dorsiflexion and plantarflexion is controlled through the talocrural joint, while the subtalar joint adds postural control to limit the amount of eversion and inversion occurring at the foot (Schoenfeld, 2010). Stable and strong foot position is critical to performing the squat safely and correctly (Baechle & Earle, 2008; Schoenfeld, 2010). Researchers indicate that approximately 20 degrees of dorsiflexion and 50 degrees of plantarflexion is expected during the squat with minimal (5 degrees) of eversion and inversion (Butler et al, 2010; Shoenfeld, 2010). The calf muscle group, gastrocnemius and soleus, also known as triceps surae concentrically contract during plantarflexion and an eccentric contraction occurs during dorsiflexion (Butler et al, 2010; Schoenfeld, 2010). The primary role of the ankle joint is to facilitate the movement from the lowest anatomical structure involved in the exercise and provide a base of support for the main actions occurring at the knee and hip to safely occur (Baechle & Earle, 2008; Butler et al, 2010; & Schoenfeld, 2010). The center of pressure about the ankle joint

shifts from mid-foot to the heel to the toes during the squat movement (Chapman, 2008; Schoenfeld, 2010). (None of the research reviewed for this current study indicated if longer limb length impacted center of pressure displacement at the ankle, knee, or hip joints) Gastrocnemius activity is connected to both the ankle and knee joint and is a bi-articulated muscle serving both joints (Schoenfeld, 2010). The gastrocnemius is responsible for plantar flexion and assisting with knee flexion; also acts as a knee stabilizer (Butler et al, 2010; Schoenfeld, 2010). Research indicates that muscle activity in the gastrocnemius increases as flexion increases and decreases as the knee extends (Butler et al, 2010; Robertson et al, 2008; & Schoenfeld, 2010). As was found with the hamstrings, the gastrocnemius muscle has a constant lengthening component because of its dual roles to two joints, which makes it isometric during the squat (Butler et al, 2010; Robertson et al, 2008; & Schoenfeld, 2010). Conversely, the soleus is only a plantar flexor and is more active than the gastrocnemius during the squat, especially during increases in flexion (Butler et al, 2010; Schoenfeld, 2010).

Adverse Characteristics

Ailments or weakness in anatomical structure at the ankle have shown to impact knee performance during squat performance because of the lack of stability in base support and associated muscles, such as the gastrocnemius (Robertson et al, 2008; Schoenfeld, 2010). Instability in the ankle can lead to improper squat technique that can impact all other anatomical facets superior to the ankle (Robertson et al,

2008; Schoenfeld, 2010; & Strutzenberger et al, 2010). For example, compromises in the ankle show that the heels tend to elevate off the ground (Schoenfeld, 2010).

Participants in the squat are instructed to maintain heels on the ground throughout the squat (Baechle & Earle, 2008; Schoenfeld, 2010). When heels are elevated, other areas in the knee and hip have to compensate putting more undue stress on those areas, and, theoretically, increasing the risk of injury (Robertson et al, 2008; Schoenfeld, 2010; & Sinclair et al, 2014). Medial knee displacement has been shown to occur in a higher prevalence of individuals that have a limited range of motion performing dorsiflexion during the squat exercise. (Schoenfeld, 2010) The ankle joint, as previously stated, plays a critical role in establishing a base of support and allowing range of motion for the squat to occur (Butler et al, 2010; Han et al, 2013; Robertson et al, 2008; Schoenfeld, 2010; & Strutzenberger et al, 2010). Finding a comfortable foot position is important to then allowing the knees to stay in line with the toes (Schoenfeld, 2010). Keeping the squat lifter's heels on the ground throughout the entire exercise is an important component to ensuring the lifter perform the squat exercise safely and correctly (Baechle & Earle, 2008; Butler et al, 2010; Han et al, 2013; Robertson et al, 2008; Schoenfeld, 2010; & Strutzenberger et al, 2010).

The trunk and spine play an important role to help ensure the squat is performed properly and safely (Baechle & Earle, 2008; List et al, 2010; & Schoenfeld, 2010). There are twenty-four vertebral segments that compose the spine

(Schoenfeld, 2010). The spine is mobile in all three planes; flexion and extension in the sagittal plane, lateral flexion in the frontal plane, and rotation in the transverse plane (Chapman, 2008; List et al, 2010, & Schoenfeld, 2010). A large group of muscles support the spinal column to provide structural support to the upper torso and extremities (Chapman, 2008; Schoenfeld, 2010). Similar to other components, while the spine and accompanying muscles are not the primary movers of the squat, they do not want to hinder the squat by forcing the main muscles to take on additional forces in a compensatory role (List et al, 2010, Robertson et al, 2008; & Schoenfeld, 2010).

Adherence to Directions

For the best and safest squat performances to occur, facilitators of the squat should ensure strength, stability, and balance in the total body (Baechle & Earle, 2008; Schoenfeld, 2010). The main directive, when discussing the spine, when performing the squat is that an upright position is maintained throughout the exercise as much as possible. (Bachle & Earle, 2008, List et al, 2010, & Schoenfeld, 2010). If this is not possible, participants should focus on maintaining their balance by keeping their center of mass over their base of support, which is their feet. Participants are told to avoid leaning forward or to the sides (Baechle & Earle, 2008; Schoenfeld, 2010). A recommendation for those who struggle with forward lean, and consequently, increase forces to the lower back during the squat, is to increase strength in the abdominals (Schoenfeld, 2010). The increase to abdominal strength adds to spinal stabilization by stiffening the trunk (List et al, 2010; Schoenfeld, 2010).

Lastly, head position and eye directional gaze have an impact on spinal position. It is recommended for participants to keep eyes looking straight ahead or upward to prevent trunk flexion (Baechle & Earle, 2008; List et al, 2010; & Schoenfeld, 2010).

Proper foot placement is critical to performing the squat exercise with proper technique and limiting the potential risk of injury (Baechle & Earle, 2008; Han et al, 2013; Schoenfeld, 2010, & Sinclair et al, 2014). There are variations of squat position that are used by squatters, such as foot being in a straight line, shoulder width apart to a wide foot stance with toes pointed slightly outward (Han et al., 2013; Schoenfeld, 2010). The data suggested that no absolute directives on one foot position existed (Han et al, 2013; Robertson et al, 2008; Schoenfeld, 2010; Sinclair et al, 2014; & Strutzenberger et al, 2010). All that is known is that different foot positions will have different outcomes on muscle activation patterns and location and quantity of forces generated (Han et al, 2013; Schoenfeld, 2010; Sinclair et al, 2014; & Strutzenberger et al, 2010). Foot placement has been shown to significantly impact the forces generated during the movement (Han et al, 2013; Schoenfeld, 2010; Sinclair et al, 2014; & Strutzenberger et al, 2010). For example, Schoenfeld (2010) found that squatters using a wider stance compared to a narrow stance generated significantly higher patellofemoral and tibiofemoral compression forces. The narrow foot stance generates less compressive forces, but generates a greater forward knee position, which is not optimal (Schoenfeld, 2010). The other impact of foot position is the pattern by which muscles are recruited (Han et al, 2013; Schoenfeld, 2010;

Sinclair et al, 2014; & Strutzenberger et al, 2010). Depending on the training goals, muscle activation and force production is an important component to performance enhancement (Baechle & Earle, 2008; Schoenfeld, 2010; & Strutzenberger). Results from squats adopting a wider foot position show greater activity in the gluteus maximus compared to narrower stances (Schoenfeld, 2010; Strutzenberger et al, 2010). The primary movers during the squat, the quadriceps and hamstrings, do not appear to be affected by foot position when evaluating their muscular activity (Han et al, 2013; Schoenfeld, 2010; Sinclair et al, 2014; & Strutzenberger et al, 2010).

Measuring Outcomes

Electromyography (EMG) and kinetics (forces) are two ways that magnitude of muscle activation and rate of force development are quantified during the squat (Baechle & Earle, 2008; Fauth et al, 2010; Robertson et al, 2008; & van den Tillar, Andersen, & Saeterbakken, 2014). This ability to quantify results is important for facilitators because they use this data to evaluate if the athlete is properly performing the squat, track progress of adaptations over time, and identify any areas of weakness that need to be improved upon (Baechle & Earle, 2008; Brandon et al, 2011; Fauth et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). The squat elicits isometric, concentric, and eccentric muscular contractions during the exercise (Baechle & Earle, 2008; Fauth et al, 2010; Gorsuch et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). These muscular contractions are put into context by framing them against the maximum voluntary contraction (MVC) of the muscle; this

context is provided on a percentage range, typically 0% to 100%, with 100% being the maximum value in most cases (Baechle & Earle, 2008; Fauth et al, 2010; Konstantinos et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). It is expected that motor unit recruitment will increase during the squat, thus increasing amplitude from EMG (Fauth et al, 2010; Robertson et al, 2008; & van den Tillar, 2014). The same can be expected during the dynamic phases of the exercise where there is a stretch-shortening cycle present (Baechle & Earle, 2008; Fauth et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). Timing of muscle activation patterns of the squat are important to verifying the exercise is being performed properly, specifically the directive that calls for simultaneous hip and knee flexion and extension (Baechle & Earle, 2008; Brandon et al, 2011; Fauth et al, 2010; Konstantinos et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). This information is discerned from EMG data that captures the neuromuscular response from motor unit activation during the exercise (Brandon et al, 2011; Fauth et al, 2010; Konstantinos et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014).

Through the use of electromyographic capture, researchers have been able to gain understanding into the muscle activation patterns of each muscle involved with the squat (Baechle & Earle, 2008; Brandon et al, 2011; Fauth et al, 2010; Konstantinos et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). The muscles of the shank were shown to provide opposite contractions where the soleus produced an eccentric contraction and the gastrocnemius contracted concentrically

during the descent movement of the squat (Brandon et al, 2011; Fauth et al, 2010; Konstantinos et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). As referenced earlier to the knee, the muscle activity shows an approximate 25% of MVC muscle activity to concentrically contract to unlock the knee with contributions from the gastrocnemius, semitendinosus, and biceps femoris (Robertson et al, 2008). The muscle activity of the knee transitions to an eccentric muscle contractions for the rest of the downward movement (Brandon et al, 2011; Fauth et al, 2010; Konstantinos et al, 2010; Robertson et al, 2008; & van den Tillar et al, 2014). Studies have shown that after the initial unlocking of the knee, the quadriceps muscle group acts eccentrically and EMG activity increases as the downward movement continues (Brandon et al, 2011; Fauth et al, 2010; Robertson et al, 2008; Schoenfeld, 2010; & van den Tillar et al, 2014). Gluteus maximus and hamstrings contract eccentrically throughout the downward movement of the squat (Brandon et al, 2011; Robertson et al, 2008; Schoenfeld, 2010; & van den Tillar et al, 2014). During the upward movement phase of the squat, the simultaneous extension of the ankle, knee, and hip joints produced varied muscular contractions (Brandon et al, 2011; Robertson et al, 2008; Schoenfeld, 2010; & van den Tillar et al, 2014). Hip, knee, and ankle extensor muscles all performed concentric work during the upward movement phase of the squat (Robertson et al, 2008). The ankle relies on the soleus to contract concentrically to extend the ankle in the upward phase (Robertson et al, 2008; Schoenfeld, 2010). The gastrocnemius's bi-articulation between the knee and ankle

limit its muscular activity contributions and is found to be contracting eccentrically in the ascent phase (Brandon et al, 2011; Robertson et al, 2008; Schoenfeld, 2010; & van den Tillar et al, 2014). The knee also saw a partial contribution from the quadriceps (Robertson et al, 2008; Schoenfeld, 2010). The vasti muscle group (lateralis, medialis, and intermedius) contracts concentrically while the rectus femoris acts eccentrically (Robertson et al, 2008). The gluteus maximus acts concentrically at the hip during the upward movement phase of the exercise with high levels of muscular activity found early on in the ascent stage (Brandon et al, 2011; Fauth et al, 2010; Robertson et al, 2008; Schoenfeld, 2010; & van den Tillar et al, 2014). The research conflicts on the role of the hamstring muscle group during the upward movement phase. Robertson et al (2008) states that the hamstrings act in an antagonistic manner and contract eccentrically. Schoenfeld (2010) found that the hamstrings to only to be “moderately” active because of the constant muscle length throughout the squat rendering a constant force output. Schoenfeld (2010) discusses the hamstrings role as a hip extensor and a knee flexor, but does not define the type of muscle contraction during the ascent phase the same way Robertson (2008) does. The timing of when the squat exercise is performed is important to the kinematic, kinetic, and electromyography results gained from the exercise. Specifically, alterations in results have been found when the exercise is performed under a fatigued state.

Researchers have found that knee instability becomes more prominent with the onset of fatigue, which could make the participant more susceptible to injury (Butler et al, 2010; Cortes et al, 2011; Han et al, 2013; Schoenfeld, 2010). Knee location and position veers away from inline recommendations to the toe and staying in the sagittal plane during hip and knee flexion and extension (Cortes et al, 2011; Han et al, 2013; & Schoenfeld, 2010). In other words, as fatigue becomes more prevalent, the muscles that support knee position become less active, and the knee begins to become unstable, and facilitators of the exercise might see the knee point outward or inward; neither case is desired as it can lead to injury (Butler et al, 2010; Cortes et al, 2011; Han et al, 2013; Schoenfeld, 2010; & Sinclair et al, 2014).

The spinal region, particularly in the lumbar area, do not handle fatigue well and will see supporting muscles of the lower back fail sooner than other muscles during the squat (List et al, 2010; Schoenfeld, 2010). Another consideration of the onset of fatigue is the displacement of where the work is trying to be done (List et al, 2010; Robertson et al, 2008; & Schoenfeld, 2010). Compensatory forces on other regions increase the stress in those areas when other muscles fail, especially if there is a load involved with the movement (List et al, 2010; McBride et al, 2011; Schoenfeld, 2010; & Sinclair et al, 2014). As stated previously, facilitators should ensure total body strength throughout to help aid the subject to perform the squat properly and safely (Baechle & Earle, 2008; Schoenfeld, 2010). Using proper technique, and not compromising that technique with the onset of fatigue, is

important to mitigating the risk of injury (Baechle & Earle, 2008; Cortes et al, 2011; Han et al, 2013; McBride et al, 2011; & Schoenfeld, 2010).

Ground Reaction Forces

The understanding of ground reaction forces and how they are influenced by the squat exercise is important to understanding if the exercise is being performed safely and track if the squatter is improving their power production (Baechle & Earle, 2008, Chapman, 2008; Fauth et al, 2010, Wurm et al, 2010). Quantifying ground reaction forces and rate of force development are two kinetic components that allow researchers to track power production of participants in the squat (Chapman, 2008; Fauth et al, 2010; McBride et al, 2011; & Wurm et al, 2010). A comparison of similar exercises to the squat (ie deadlift, lunge, and step up) shows that the squat generates the highest ground reaction forces both concentrically and eccentrically (Fauth et al, 2010; Wurm et al, 2010). Conversely, the rate of force development concentrically for the squat was the slowest of the exercises being compared (Fauth et al, 2010; Wurm et al, 2010). These outcomes do match what is expected from the force velocity curve, which indicates that the slower movements result in maximal strength development (Chapman, 2008; Fauth et al, 2010; & Wurm et al, 2010). Even though the rate of force development is slower, the motor unit recruitment is greater than the other exercises (Fauth et al, 2010; Wurm et al, 2010). Data collected from force plates shows that the addition of a load and the amount of the load can significantly impact the ground reaction forces and rate of development of the squat;

also, the position of the load, for example, posterior versus anterior (Fauth et al, 2010; Kim, 2014; Shoenfeld, 2010; & Wurm et al, 2010).

There is a gap present in the research when it comes to the impact that anthropometrics has on back squat performance. A more specific evaluation of body segments relative to overall height may lead to questions about how anthropometric measures may impact kinematic, kinetic, and electromyography results from those performing the squat exercise. Anthropometric studies are common in research done with elite athletes (Carvalho, Mourão, & Abade, 2014; Chaouachi, Brughelli, Levin, Boudhina, Cronin, & Chamari, 2009; Justin, Vuleta, Pori, Kajtna, & Pori, 2013; & Nikolaidis, Afonso, & Busko 2015). Researchers have theorized about the impact of anthropometric measures on sports performance and injuries, and they have done this by profiling athletes. Depending on the sport demands, or demands by position, height could be a contributing factor to success in the sport or a detriment (Carvalho et al, 2014; Chaouachi, et al, 2009; Justin, et al, 2013; & Nikolaidis et al, 2015). As it relates to the squat exercise, recommendations from the NSCA do not assign squat technique to the individual, but rather to the group, as long the participants are healthy (Baechle & Earle, 2008). A comparative analysis of kinematic, kinetic, and electromyography results of groups of varying height performing the squat could validate the “one group” assignment of the exercise, or lead to a conversation about different instructions on the squat for different groups of heighted people. There is a

possibility that the results of the present study could lend itself to a conversation about athletes not performing the squat exercise at all.

User Dependent Plasticity

User dependent plasticity, also known as activity-dependent plasticity, is the development of neuroplasticity by way of learning through experience. Neuroplasticity is the term given to long term changes to the brain. User dependent plasticity, along with neuroplasticity, is a motor control concept that is caused through the engagement in functional movements over time (Butefisch, Davis, Wise, Sawaki, Kopylev, Classen, & Cohen, 2000; Mawase, Uehara, Bastain, & Celnik, 2017). The resultant neuroplasticity creates improved motor function that allows individuals to enhance their performance. For example, with the back squat exercise, it would not be surprising for beginners to have inadequate range of motion or lack simultaneous hip and knee flexion and extension. Over time, however, with continuous engagement in the maneuver, it is expected that improvements in range and motion & timing will occur as a part of the learning process. Thus, the brain gains long term adaptations to execute improved motor patterns.

Enhanced motor control and learning is achieved through the signaling processes of the brain where neurons disseminate information to the rest of the body. The reorganization over time of these signals to make movement more efficient is important to the development of neuroplasticity. Experience is an important contributor to these changes occurring because of the development of motor

memories. When considering a movement, it can be understood that individuals that have engaged in the movement repeated times, will have a higher level of training status because of their enhanced changes in the motor cortex because of the development of motor memories (Butefisch et al, 2000; & Mawase et al, 2017).

Side Dominance

Individuals who engage in resistance training need to focus on developing symmetry between both the right and left sides of their bodies. The key factor for this is injury prevention. Weakness, typically in the non-dominant side, can lead to injury chronic pain. Common anatomical locations for this pain are the lower back and hip regions. Additionally, with weakness in one side, possible compensation in the stronger side can lead to injury as well. The second key consideration for the importance of side balance is performance enhancement (Newton, Gerber, Nimphius, Shim, Doan, Robertson, Pearson, Craig, Hakkinen, & Kraemer, 2006). Athletes need to strive to achieve goals of strength equality between both sides, even though the non-dominant side may not thought to be as critical. For example, a soccer player that is kicking a ball. The strength in the plant leg/foot is just as important as the strength in the swing leg/foot when kicking a soccer ball. So, for soccer players, the back squat exercise is an appropriate exercise to symmetrically develop both the left and right sides of the musculature.

Chapter III

METHODS

Institutional Review Board Approval

Per Seton Hall University protocol, approval was sought and gained from Hackensack University Medical Center Institutional Review Board, Hackensack, New Jersey. The project was approved (Appendix A).

Study Design

The study was a correlational design with three independent variables, which were hip width to height, torso length to height (anthropometric ratios) & side (left and right hip) differential, and four dependent variables (angles, moments, power, and force) in the three cardinal planes of motion.

Recruitment Strategy

Recruitment fliers were placed near the entrance of the fitness center on Seton Hall University's campus (South Orange, NJ) and the posted near the entrance of a local recreational center (Summit, NJ). Subjects self-identified themselves to the principal investigator by sending the PI an email. The PI followed up on the email from the potential subject and scheduled a phone screen (Appendix B). The PI then called the potential subject at the schedule time and read a phone script to inform the potential subject about the study and to assess for inclusion/exclusion criteria.

Subjects

Potential subjects self-identified by emailing the principal investigator. The PI performed a phone screen dictated by a standardized script (Appendix I). Additionally, the PI sent the potential subject an electronic copy of the informed consent and HIPAA forms (Appendix C) for review prior to data collection. Thirty-one potential subjects were identified for the study, but only twenty healthy male (25.85 ± 3.81) subjects completed the study. The eleven subjects that did not participate due to scheduling issues, not meeting all inclusion criteria, and loss of interest in the study. The total sample of twenty subjects is a widely accepted sample size for movement science studies. The sample size of twenty subjects is also comparable to similar studies as Caruso et al (2009) had a sample size of 18 and Gullett et al (2009) had 15 subjects.

Inclusion criteria

Male

Aged 18 to 50

BMI < 25

Must have at least two years experience in the back squat, deadlift, and hex bar deadlift

Apparently healthy (free from musculoskeletal injury in the past 6 months)

No chronic history of injury or illness

Exclusion criteria

Non-males

Younger than 18 or older than 50

BMI > 25

Inexperienced lifters

Currently injured or ill

Past history of chronic injury or illness

Independent Variables

Anthropometric measurement ratio

- Hip width to height
- Torso length to height

Side

- Left side
- Right side

Dependent variables

Range of motion between hips & thighs (degrees) in the three cardinal planes of motion

Joint moments (Newton Meters) in the three cardinal planes of motion

Joint power (Watts) in the three cardinal planes of motion

Joint Force (Newtons) in the three cardinal planes of motion

Procedures

Overview

Subjects were required to only attend one, ninety minute session to collect the data for this study. On the day of the data collection, many separate events occurred. The following is a list of those events. First, prior to the arrival of the subject, the motion capture system was stabilized and cameras were calibrated as per manufacturer's recommendations. Next, participants signed the informed consent and HIPAA forms (Appendix C). If the subject passed four prescreens, which were the Physical Activity Readiness questionnaire (Appendix D), prone instability test, overhead squat test (Appendix E), and a BMI assessment, the subject was then prepped for data collection. The data preparation phase included having the subject change into appropriate attire, which consists of a tight fitting top, tight shorts or pants, and sneakers. Additionally, during this time, all the necessary anthropometric measurements needed for the study were taken. This included all measurements that were needed to be input into the software to ensure marker identification accuracy. After that, the subject was lead through a scripted warm-up by the PI (see Appendix F). Next, the reflective markers for the motion analysis cameras were attached to the subject using double-sided, hypo-allergenic adhesive tape. Each participant was given detailed instructions on the back squat exercise (Appendix G). The data collection

then began. At the conclusion of the data collection, the subject was led through a scripted cool-down (Appendix H). More specifics are listed below.

Details of Events

Body weight, height, and anthropometric measurements

The participants in the study were asked to remove footwear and empty pockets in order for their height and weight. The PI measured the subject using a standard tape measure against the wall. Weight was taken on a standard electronic floor scale (weight was taken in kilograms (kgs). The scale was a Health o meter Dial Scale Model 155 (Bridgeview, Illinois). Height and weight were used to calculate Body Mass Index (BMI). All subjects had a BMI less than 25. Subjects with a BMI greater than or equal to 25 were excluded from the study due to the interference that excess fatty tissue presents to both the markers, particularly the ASIS markers. If a participant cleared both the PAR-Q and BMI prescreens, he was moved on to the data collection phase of the testing. The participant was asked to wear form fitting, bicycle-type shorts or pants, a tight form fitting shirt, and athletic shoes during the study. Anthropometric measurements were also taken using the standard measuring tape. The measurements that were taken were the hip width, defined as the lateral length across the subject's right anterior superior iliac spine to the left anterior iliac spine, and torso length, which was defined as the length from the acromioclavicular joint to the anterior superior iliac spine. All length measurements

were taken in millimeters (mm). Other important anthropometric measurements were taken using a caliper called “Anthropometer” with model number 01291 from the Lafayette Instrument Company (Lafayette, Indiana). The following measurements were input into the Vicon Nexus software to accurately identify marker locations, which are used to estimate joint centers. The following measurements were taken in millimeters using the caliper: ankle width (defined as the mediolateral distance across the malleoli, measured with the subject standing), knee width (defined as the mediolateral distance across the line of the knee axis, measured with the subject standing), shoulder offset (defined as the vertical distance from the center of the glenohumeral joint to the marker on the acromionclavicular joint), elbow width (defined as the distance between medial and lateral epicondyles of the humerus), wrist width (defined as the distance between the ulnar and the radial styloids, hand thickness (defined as the distance between the dorsal and palmar surfaces of the hand, and inter-ASIS distance (defined as the distance between the position of the right and left ASIS markers). Leg length (defined as the full leg length measured between the ASIS and the medial malleolus, via the knee joint, measured with the subject standing) was measured using a standard measuring tape.

The next part of the process was the placement of the reflective markers. Forty-one reflective markers were placed over various parts of your body. Through palpation of specific bony landmarks, the PI determined the exact placement motion detection markers should be placed and placed forty-one reflective markers on the

subject's person. The markers were affixed using hypo-allergenic double-sided adhesives.

After all markers were placed on the subject, the PI led the subject through a warm-up protocol (see Appendix E) that prepared him for physical activity.

Next, the subject was shown the movements or action that were used for testing (see Appendix F), and the subject was allowed as many repetitions as they needed for familiarization. Based on the responses to the supplemental questions from the PAR-Q (see Appendix D), the researcher determined the load based off of 1 repetition maximum. The subject performed three warmup repetitions of the back squat at 50% of 1RM. The subject was given a three minute break. After three minutes, the subject performed five, one repetition sets of 80% of 1RM back squat (Caruso et al, 2009). The subject was instructed to perform all exercises according to the guidelines read to them, which follow the recommendations of the NSCA (see Appendix F).

Once the subject completed the data collection, the subject was offered water from the water fountain which was directly outside the laboratory door. The final task was a five minute cool-down adapted from recommendations from the NSCA. This cool-down was scripted and lead by the PI (Appendix G).

Vicon Bonita Capture System

Bonita cameras (Vicon Motion Systems Ltd, Colorado Springs, CO) operated at a sampling frequency of 100 frames/s to capture the movement of the markers

placed on the body. Markers were placed on the subject to acquire anatomical locations. Forty-one 9 millimeter markers were used to track the movements during the exercise.

The exact location of the markers is as follows: right front head (located approximately over the right temple), left front head (located approximately over the left temple), right back head (placed on the back of the head, roughly in a horizontal plane of the front head markers), left back head (placed on the back of the head, roughly in a horizontal plane of the front head markers), 7th cervical vertebrae (spinous process of the 7th cervical vertebrae), 10th thoracic vertebrae (spinous process of the 10th thoracic vertebrae), clavicle (jugular notch where the clavicles meet the sternum), sternum (xiphoid process of the sternum), right back (placed in the middle of the right scapula), left shoulder (placed on the acromio-clavicular joint), left upper arm marker (placed on the upper between the elbow and shoulder markers), left elbow (placed on lateral epicondyle approximating elbow joint axis), left forearm marker (placed on the lower arm between the wrist and elbow markers, asymmetrical to right forearm marker), left wrist marker A (left wrist bar thumb side), left wrist marker B (left wrist bar pinkie side), left finger (placed on the dorsum of the hand just below the head of the second metacarpal), left anterior superior iliac spine (placed approximately 50 mm laterally away from the left ASIS), left posterior superior iliac spine (placed directly over the left PSIS), left knee (placed on the lateral epicondyle of the left knee), left thigh (placed over the lower lateral 1/3 surface of the thigh, just

below the swing of the hand), left ankle (placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis), left tibial wand marker (placed over the lower 1/3 of the shank to determine alignment of the ankle flexion axis), left toe (placed over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot), left heel (placed on the calcaneus at the same height above the plantar surface of the foot as the toe marker), right shoulder (placed on the acromio-clavicular joint), right upper arm marker (placed on the upper between the elbow and shoulder markers, asymmetrical to left upper arm), right elbow (placed on lateral epicondyle approximating elbow joint axis), right forearm marker (placed on the lower arm between the wrist and elbow markers, asymmetrical to left forearm marker), right wrist marker A (right wrist bar thumb side), right wrist marker B (right wrist bar pinkie side), right finger (placed on the dorsum of the hand just below the head of the second metacarpal), right anterior superior iliac spine (placed approximately 50 mm laterally away from the right ASIS), right posterior superior iliac spine (placed directly over the right PSIS), right knee (placed on the lateral epicondyle of the right knee), right thigh (placed over the lower lateral 1/3 surface of the thigh, just below the swing of the hand), right ankle (placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis), right tibial wand marker (placed over the lower 1/3 of the shank to determine alignment of the ankle flexion axis), right toe (placed over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot), right

heel (placed on the calcaneus at the same height above the plantar surface of the foot as the toe marker), and right & left iliac crest. Importantly, due to the nature of the back squat exercise, the visibility of the anterior superior iliac spine (ASIS) markers is comprised at the bottom of the movement. In order to correct for this lack of visibility, it was crucial to add the left and right iliac crest markers. The additional markers to the pelvic girdle allowed for the lost trajectories of the ASIS to be filled using the body pattern fill feature within the gap fill tab, which is a part of the Nexus 2.5 software. The filling of the lost gaps occurs during the data processing phase of the data collection.

Kinematic signal processing

After the signal was captured, it was processed through the dynamic gait pipeline, which is offered as a part of the Vicon Nexus software. This pipeline includes a Woltering filter, which helps to eliminate any erroneous signals. Next, all gaps were filled to ensure a continuous signal throughout the movement. The processed signal was exported to Microsoft Excel. In Excel, the signal was charted on a line graph and peak values for angle movements were determined (see Chapter IV, Results). The kinematic data points that were used for analysis were the data points that corresponded with the peak flexion angle in the left and right hip for all three cardinal planes of motion. These angle measurements corresponded with the bottom of the movement (Schoenfeld, 2010).

Kinetics

Subjects were asked to step on separate Bertec (Columbus, Ohio) force plates (Model FP 4060-08) with each foot, which allowed the researchers to record ground reaction forces. The force data was gathered through an amplifier, which sends the signal through an analog to digital convertor before it was processed by the computer software.

The two Bertec force plates used strain gauge transducers to collect the raw force signal. The acquisition system captured a 16-bit signal in analog form. The analog signal was processed through an analog to digital board (A/D) in the main Laboratory PC, which allowed the signal to process into Vicon Nexus. The signal was captured in millivolts for all three axis (X, Y, & Z), but only the Z coordinate is calculated.

Kinetic data processing

Inverse dynamics, via Vicon Nexus 2.5, were used to determine the kinetic values. The kinetic data was exported to Microsoft Excel in the same manner the kinematic data was. The dynamic gait pipeline, utilizing a Woltering filter, was run on the raw signal to “clean-up” the signal. The exported signal in Excel offers the numerical data for the kinetics that allows the forces to be graphed and peak values to be obtained.

Filtering and Filling Gaps

It was assumed that when the data was first collected, it was imperfect because the true signal was accompanied by external noise and possible gaps may

exist for certain parts of the movement that were not able to be accurately captured. Due to this circumstance, the data were filtered and the gaps were filled utilizing an auto-fill function within the Nexus software as well as manual pattern gap fill. This study utilized the Plug-in Gait marker set, which is advantageous as it allowed multiple processes and filters to be applied within the Nexus software. The first step to processing the data was creating the static model. Next, the dynamic model was processed through the pipeline. The software applies a Woltering filter to the raw data to help smooth the data. The Woltering filter is a quantic spline routine, which also fills gaps as a part of its processing capabilities. After the Woltering filter is applied, it was necessary to check errors that still remained. If the capture was strong to begin with, it was possible that the Woltering filter smoothed all signals, eliminated all erroneous markers, and filled all gaps. In the event that gaps and unidentified markers were still present, it was necessary to manually fill gaps and eliminated errant markers. This was done utilizing another function in Nexus that allowed gaps and missing trajectories to be filled and unused markers to be deleted.

Importantly, due to the nature of the squat movement, it was expected that the cameras would have issues seeing the ASIS markers, particularly at the bottom of the descent. To solve for this problem, the marker set was modified and two additional markers were added: right and left iliac crest. The addition of these markers allowed for the cameras to track the pelvic girdle throughout the whole movement. During the gap fill process, the pattern body was used where an iliac crest and the two

posterior superior iliac crests were chosen to fill the ASIS gaps. Once all the gaps were filled and all markers were accounted for in their proper location, the data was ready for export.

Instrumentation & Equipment

Six high speed motion capture system (Vicon Bonita Cameras, 1 L-wand, 39 reflective markers)

Two Bertec Force Plates

One 20.5 kg (45 pound) Olympic straight bar from USA Sports by Troy
Barbell (Chrome)

One 20.5 kg (45 pound) hex bar

115.9 kgs (255 pounds) of free weight: two 2.27 kgs (5 pound) plates, two 4.5 kgs (10 pound) plates, two 11.4 kgs (25 pound) plates, two 15.9 kgs (35 pound) plates), and two 20.5 kgs (45 pound) plates from USA Sports by Troy
Barbell

Two free standing adjustable squat stands, solid steel from Best Choice
Products

Data Analysis

The data was acquired using Vicon Nexus 2.5. The processed kinematic and kinetic data was exported to excel. In excel, the data from the middle three trials from each subject's back squat trial was averaged to determine kinematic and kinetic outcome values for both the left and right hip. The acquired data was analyzed using

SPSS v24 software. Normality was assessed in SPSS v24, and violations of normality were found at five data locations. Due to this result, non-parametric analyses were run. To assess if a relationship was present between the anthropometric ratios and the kinematic & kinetic results, Spearman's correlation coefficient (rho) test (Field, 2009) was run. To assess side differential, Wilcoxon signed-rank test was performed. Post hoc G*Power analysis was performed on any data that showed significance. The G*Power Analysis was used to determine if the analysis met the .80 threshold for power.

Chapter IV

Results

The results from this study showed minimal significant findings of the thirty-six separate analyses that were run. A main focus of this study was to investigate if a relationship was present between anthropometric ratios and kinematic & kinetic outcomes of the back squat exercise in either the left or right hip. The study quantified these outcomes by gathering angle, moment, power, and force measures in the three cardinal planes of motion (sagittal, frontal, and transverse). No relationship was found in either side of the hip to the hip width to height ratio and the torso length to height ratios. This indicates that amongst this highly trained group of subjects, body proportionality was not a factor. For the left and right side comparison, four of the twelve analyses showed significance. These results are important because they show imbalances and lack of symmetry, which could increase the risk of injury and be detrimental to performance enhancement.

Table 1

Subject Demographic Data

	Mean	Standard Deviation
Age (years)	25.85	3.81
Height (mm)	1772.5	80.25
Height (in.)	69.78	3.16
Hip width to Height (%)	14.6	1.4
Torso length to Height (%)	26.4	2.2
Weight (kgs)	78.16	5.86
Weight (lbs.)	171.95	12.89
Squat Load Lifted (kgs)	89.66	23.23
Squat Load Lifted (lbs.)	197.25	48.9
Hip Length (mm)	259	24.09
<u>Torso Length (mm)</u>	<u>469.75</u>	<u>49.27</u>

Note. N = 20.

Subject Demographics

The subjects that volunteered for this study were well trained in the back squat exercise. This is shown by the amount of loaded lifted, on average, being approximately twenty-five pounds greater than average body weight. Of the twenty subjects, there were eighteen right-handed subjects and two left handed subjects.

Hip width to Height Relationship

An evaluation of the relationship between the hip width to height ratio (1) and the kinematic (i. angles) and kinetic (ii. moments, iii. power, and iv. force) outcomes in the sagittal (X), frontal (Y), and transverse (Z) planes in the left (a) hip was performed using Spearman's correlation coefficient (ρ).

It was hypothesized that:

Hip Width to Height Ratio and Outcomes of the Left Hip in the Sagittal Plane

H1iXa- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the left hip in the sagittal plane.

H1iiXa- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the sagittal plane.

H1iiiXa- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the sagittal plane.

H1ivXa- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the sagittal plane.

Hip Width to Height Ratio and Outcomes of the Left Hip in the Frontal Plane

H1iYa- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the left hip in the frontal plane.

H1iiYa- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the frontal plane.

H1iiiYa- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the frontal plane.

H1ivYa- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the frontal plane.

Hip Width to Height Ratio and Outcomes of the Left Hip in the Transverse Plane

H1iZa- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the left hip in the transverse plane.

H1iiZa- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the transverse plane.

H1iiiZa- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the transverse plane.

H1ivZa- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the transverse plane.

No significant relationship was found in the left (a) hip when assessing if there was a correlation between hip width to height ratio (1) and i. angle (degrees) measurements, ii. moments (Nm), iii. power (Watts), and iv. force (N) in the sagittal (X), frontal (Y), and transverse (Z) planes.

An evaluation of the relationship between the hip width to height ratio (1) and the kinematic (i. angles) and kinetic (ii. moments, iii. power, and iv. force) outcomes

in the sagittal (X), frontal (Y), and transverse (Z) planes in the right (b) hip was performed using Spearman's correlation coefficient.

It was hypothesized that:

Hip Width to Height Ratio and Outcomes of the Right Hip in the Sagittal Plane

H1iXb- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the right hip in the sagittal plane.

H1iiXb- There will be a relationship between hip width to height ratio and the moment (Nm) in the right hip in the sagittal plane.

H1iiiXb- There will be a relationship between the hip width to height ratio and the power (Watts) output in the right hip in the sagittal plane.

H1ivXb- There will be a relationship between the hip width to height ratio and the force (N) in the right hip in the sagittal plane.

Hip Width to Height Ratio and Outcomes of the Right Hip in the Frontal Plane

H1iYb- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the right hip in the frontal plane.

H1iiYb- There will be a relationship between hip width to height ratio and the moment (Nm) in the right hip in the frontal plane.

H1iiiYb- There will be a relationship between the hip width to height ratio and the power (Watts) output in the right hip in the frontal plane.

H1ivYb- There will be a relationship between the hip width to height ratio and the force (N) in the right hip in the frontal plane.

Hip Width to Height Ratio and Outcomes of the Right Hip in the Transverse

Plane

H1iZb- There will be a relationship between the hip width to height ratio and the angle (degrees) measurement in the right hip in the transverse plane.

H1iiZb- There will be a relationship between the hip width to height ratio and the moment (Nm) in the left hip in the transverse plane.

H1iiiZb- There will be a relationship between the hip width to height ratio and the power (Watts) output in the left hip in the transverse plane.

H1ivZb- There will be a relationship between the hip width to height ratio and the force (N) in the left hip in the transverse plane.

No significant relationship was found in the right (b) hip when assessing if there was a correlation between hip width to height ratio (1) and i. angle (degrees) measurements, ii. moments (Nm), iii. power (Watts), and iv. force (N) in the sagittal (X), frontal (Y), and transverse (Z) planes.

Torso length to Height Relationship

An evaluation of the relationship between the torso length to height ratio (2) and the kinematic (i. angles) and kinetic (ii. moments, iii. power, and iv. force) outcomes in the sagittal (X), frontal (Y), and transverse (Z) planes in the left (a) hip was performed using Spearman's correlation coefficient (ρ).

It was hypothesized that:

Torso Length to Height Ratio and Outcomes of the Left Hip in the Sagittal Plane

H2iXa- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the left hip in the sagittal plane.

H2iiXa- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the sagittal plane.

H2iiiXa- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the sagittal plane.

H2ivXa- There will be a relationship between the torso length to height and the force (N) in the left hip in the sagittal plane.

Torso Length to Height Ratio and Outcomes of the Left Hip in the Frontal Plane

H2iYa- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the left hip in the frontal plane.

H2iiYa- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the frontal plane.

H2iiiYa- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the frontal plane.

H2ivYa- There will be a relationship between the torso length to height ratio and the force (N) in the left hip in the frontal plane.

Torso Length to Height Ratio and Outcomes of the Left Hip in the Transverse Plane

H2iZa- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the left hip in the transverse plane.

H2iiZa- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the transverse plane.

H2iiiZa- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the transverse plane.

H2ivZa- There will be a relationship between the torso length to height ratio and the force (N) in the left hip in the transverse plane.

No significant relationship was found in the left (a) hip when assessing if there was a correlation between torso length to height ratio (2) and i. angle (degrees) measurements, ii. moments (Nm), iii. power (Watts), and iv. force (N) in the sagittal (X), frontal (Y), and transverse (Z) planes.

An evaluation of the relationship between the torso length to height ratio (2) and the kinematic (i. angles) and kinetic (ii. moments, iii. power, and iv. force) outcomes in the sagittal (X), frontal (Y), and transverse (Z) planes in the right (b) hip was performed using Spearman's correlation coefficient.

It was hypothesized that:

Torso Length to Height Ratio and Outcomes of the Right Hip in the Sagittal Plane

H2iXb- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the right hip in the sagittal plane.

H2iiXb- There will be a relationship between the torso length to height ratio and the moment (Nm) in the right hip in the sagittal plane.

H2iiiXb- There will be a relationship between the torso length to height ratio and the power (Watts) output in the right hip in the sagittal plane.

H2ivXb- There will be a relationship between the torso length to height ratio and the force (N) in the right hip in the sagittal plane.

Torso Length to Height Ratio and Outcomes of the Right Hip in the Frontal Plane

H2iYb- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the right hip in the frontal plane.

H2iiYb- There will be a relationship between the torso length to height ratio and the moment (Nm) in the right hip in the frontal plane.

H2iiiYb- There will be a relationship between the torso length to height ratio and the power (Watts) output in the right hip in the frontal plane.

H2ivYb- There will be a relationship between the torso length to height ratio and the force (N) in the right hip in the frontal plane.

Torso Length to Height Ratio and Outcomes of the Right Hip in the Transverse Plane

H2iZb- There will be a relationship between the torso length to height ratio and the angle (degrees) measurement in the right hip in the transverse plane.

H2iiZb- There will be a relationship between the torso length to height ratio and the moment (Nm) in the left hip in the transverse plane.

H2iiiZb- There will be a relationship between the torso length to height ratio and the power (Watts) output in the left hip in the transverse plane.

H2ivZb- There will be a relationship between the torso length to height ratio and the force (N) in the left hip in the transverse plane.

No significant relationship was found in the right (b) hip when assessing if there was a correlation between torso length to height ratio (2) and i. angle (degrees) measurements, ii. moments (Nm), iii. power (Watts), and iv. force (N) in the sagittal (X), frontal (Y), and transverse (Z) planes.

Left to Right Hip Side Differences

A comparison of the kinematic (i. angles(degrees)) and kinetic (ii. moments (Nm), iii. Power (Watts), and iv. Force (N)) outcomes in the sagittal (X), frontal (Y), and transverse (Z) planes in the left and right hip (3) was conducted using Wilcoxon's signed-rank test.

It was hypothesized that:

Differences between Left and Right Hip Outcomes in the Sagittal Plane

H3iX- There will be no difference in the i. angle measurements outcomes between the left and right hip in the sagittal plane.

H3iiX- There will be no difference in the ii. moment outcomes between the left and right hip in the sagittal plane.

H3iiiX- There will be no difference in the iii. power outcomes between the left and right hip in the sagittal plane.

H3ivX- There will be no difference in the iv. force outcomes between the left and right hip in the sagittal plane.

Differences between Left and Right Hip Outcomes in the Frontal Plane

H3iY- There will be no difference in the i. angle measurements outcomes between the left and right hip in the frontal plane.

H3iiY- There will be no difference in the ii. moment outcomes between the left and right hip in the frontal plane.

H3iiiY- There will be no difference in the iii. power outcomes between the left and right hip in the frontal plane.

H3ivY- There will be no difference in the iv. force outcomes between the left and right hip in the frontal plane.

Differences between Left and Right Hip Outcomes in the Transverse Plane

H3iZ- There will be no difference in the i. angle measurements outcomes between the left and right hip in the transverse plane.

H3iiZ- There will be no difference in the ii. moment outcomes between the left and right hip in the transverse plane.

H3iiiZ- There will be no difference in the iii. power outcomes between the left and right hip in the transverse plane.

H3ivX- There will be no difference in the iv. force outcomes between the left and right hip in the transverse plane.

Significant differences between the left and right hip were found in four comparisons: Power in the sagittal plane ($p = .003$), angle in the frontal plane ($p = .002$), force in the frontal plane ($p = .032$), and power in the transverse plane ($p = .001$). No significant differences were found in any of the other comparisons.

Table 2

Correlational Analysis (Spearman's Rho) for the Kinematic (Angles) and Kinetic (Moment, Power, and Force) results of the Left Hip

Variable	Mean	SD	Hip Width/Height Ratio		Torso Length/Height Ratio	
			Sig (P)	Spearman's (rho)	Sig. (P)	Spearman's (rho)
Sagittal						
Angle (deg)	89.83	5.53	0.62	-0.118	0.582	0.131
Moment (Nm)	-175.01	14.3	0.221	-0.287	0.91	0.027
Power (Watts)	157.26	8.34	0.405	0.197	0.758	-0.074
Force (N)	161.67	12.81	0.912	0.026	0.262	0.263
Frontal						
Angle (deg)	-31.68	6.46	0.125	-0.355	0.821	0.054
Moment (Nm)	-94.85	6.13	0.666	0.103	0.855	-0.044
Power (Watts)	11.91	1.51	0.109	0.369	0.682	-0.098
Force (N)	162.79	8.66	0.554	0.141	0.561	0.138
Transverse						
Angle (deg)	21.97	5.42	0.638	0.112	0.673	-0.101
Moment (Nm)	34.87	1.91	0.383	0.206	0.424	-0.189
Power (Watts)	6.69	0.565	0.967	-0.01	0.416	0.192
Force (N)	-719.05	45.75	0.722	0.085	0.552	-0.141

Note. No significant relationship was found between the ratios and outcomes.

Table 3

Correlational Analysis (Spearman's Rho) for the Kinematic (Angles) and the Kinetic (Moment, Power, and Force) results of the Right Hip

Variable	Mean	SD	Hip Width/Height Ratio		Torso Length/Height Ratio	
			Sig (P)	Spearman's (rho)	Sig. (P)	Spearman's (rho)
Sagittal						
Angle (degrees)	89.6	3.92	0.319	0.235	0.102	-0.376
Moment (Nm)	-175.1	14.3	0.91	0.027	0.221	0.027
Power (Watts)	157.67	8.55	0.673	-0.101	0.389	0.204
Force (N)	160.29	8.54	0.301	0.244	0.9	0.03
Frontal						
Angle (degrees)	28.11	5.56	0.093	0.385	0.32	-0.234
Moment (Nm)	94.78	5.88	0.875	0.038	0.806	-0.059
Power (Watts)	12.01	1.54	0.858	-0.043	0.123	0.357
Force (N)	162.93	8.61	0.427	0.188	0.518	0.153
Transverse						
Angle (degrees)	-21.01	4.4	0.481	-0.167	0.128	0.352
Moment (Nm)	34.99	1.83	0.431	-0.186	0.376	0.209
Power (Watts)	6.85	0.62	0.58	0.132	0.765	0.071
Force (N)	-719.2	45.6	0.552	-0.141	0.722	0.085

Note. No significant relationship was found between the ratios and outcomes.

Table 4

Wilcoxon signed-rank test to compare left and right hip outcomes.

Variable	Left Hip	Right Hip	Sig. (p < .05)	Z-score	Effect Size
Sagittal (X)					
i. Angle (deg)	89.83	89.6	0.881	0.149	0.033
ii. Moment (Nm)	-175.01	-175.1	0.247	-1.158	0.259
iii. Power (Watts)	157.26	157.67	0.003*	-2.931	0.655
iv. Force (N)	161.67	160.29	0.49	0.691	0.155
Frontal (Y)					
i. Angle (deg)	-31.68	28.11	0.002*	3.136	0.701
ii. Moment (Nm)	-94.85	94.78	0.563	0.579	0.129
iii. Power (Watts)	11.91	12.01	0.121	-1.55	0.347
iv. Force (N)	-162.79	162.93	0.032*	-2.148	0.48
Transverse (Z)					
i. Angle (deg)	21.98	21.01	0.526	0.635	0.142
ii. Moment (Nm)	34.87	34.99	0.135	-1.494	0.334
iii. Power (Watts)	6.69	6.85	0.001*	-3.176	0.71
iv. Force (N)	-719.05	-719.2	0.097	-1.662	0.372

Note. Significance was found in four comparisons of the means between the left and right side using non-parametric analysis (Wilcoxon signed-rank test). Power in the sagittal plane was significant at .003 with a medium to large effect size (.655) and power was significant in the transverse plane at .001 with a large effect size of .71.

Chapter V

Discussion/Future Recommendations/Conclusion

Findings/Results

The results of this research were meaningful, despite the relatively low amount of significance found throughout the statistical analysis. The data that was collected and analyzed begins a conversation about the relationship that anthropometrics may have on injury risk and performance. It is important to note that a significant difference was found in four comparisons of data when comparing the means of the left and right hip. These differences indicate that there was an issue of side difference, which may increase the risk of injury and inhibit the enhancement of performance for the athlete.

Range of motion

The subjects, in general, were an experienced and talented group of back squatters that self-selected into the study. This is known from their results. For example, the performance results are impressive. The subjects were instructed to perform the squat to ninety degrees of hip flexion (Baechle & Earle, 2008; Butler et al, 2010; & Schoenfeld, 2010) and they were almost at the precise level of hip flexion that was requested as the mean in the left hip was 89.83° and 89.6° in the right hip. In a similar study conducted by Sinclair et al (2014), the group of subjects performing the back squat achieved 86.39 degrees of peak flexion, which is similar to the results found in the present study. The Sinclair et al (2014) study had their Subjects performing 70% of 1RM, which is less than the 80% of 1 RM that was used

in the present study, which shows that the subjects of the present study were achieving a greater range of motion while under a greater amount of stress from a heavier load.

Load

As stated above, the average load that was lifted was 80% of 1 repetition maximum (1 RM) was approximately twenty-five pounds greater than body weight. In comparison to a study that focused on the front squat, a group of Division I football players were front squatting 10 more pounds at 80% 1RM (Caruso et al, 2009). It is known that front squat usually calls for less load than the back squat, but it shows the level of the ability of the participants in the present study compared to a group of highly trained college, American football players.

Prescreens

The subjects cleared four prescreens that verified the inclusion criteria of the study. First, the body mass index (BMI) was chosen to be less than 25 because extraneous subcutaneous tissue that is usually found in those classified as overweight or obese may have obstructed the sight line of the motion analysis cameras and the markers. The prone instability test was chosen to verify that no pain was found in the lower back, which is an anatomical region that is commonly complained about. The physical activity readiness questionnaire (PAR-Q) is a common set of questions that verify the overall health of the subjects. Lastly, the Overhead Squat Test was utilized

to ensure that the subjects could perform the maneuver free of dysfunction and without the need for a modification. The subjects that were included in this study passed these four prescreens. This was important because it eliminated potential subjects from the study that may have had results that were due to other factors such as pain, poor health, and/or limited range of motion, rather than from the outcomes of the back squat itself.

Anthropometric Ratios

The anthropometric results revealed noteworthy findings. There was limited variability amongst the subject pool. Specifically, when reviewing the anthropometric ratios of the hip width to height, fourteen of the twenty participants were within the standard deviation of the mean, six subjects were one standard deviation away from the mean, and no subject was two or more standard deviations away from the mean. The torso to height ratio indicated a similar trend where the thirteen of the twenty subjects were within the standard deviation of the mean, seven were one standard deviation from the mean, and no subject was two or more standard deviations away from the norm. This is important as the focus of the study is exploring these anthropometric ratios and there is a lack of variance amongst the highly trained subjects. This raises interesting questions about the subjects themselves. The lack of variance of the anthropometrics may be a part of the reason why a lack of significance was found when investigating if a relationship was present

between the anthropometric ratios and the squat outcomes. That remains to be seen as more comparative data is needed, but it leads to a review of whom should be recruited into the study. These results are only from the hip complex and do not indicate what the response will be in the other joint complexes. Lastly, no other research has identified this issue of lack of variance of anthropometric ratios, and this has to do with the lack of investigation into this area of interest when it comes to the back squat.

There have been other studies that have explored anthropometrics. However, these studies have noticeable differences from this study. For example, a study performed by Mayhew, Piper, and Ware (1993) investigated the correlation of strength performance and resistance trained athletes. This study found that the more joint complexes involved in an exercise the less impactful the relationship between anthropometric dimensions and strength. This shows that a complex exercise involving the entire body, like the back squat, is less likely to allow strength to be predicted from anthropometrics, once a relationship is found, than an exercise like the bench press that involves fewer anatomical structures.

The idea of using anthropometric ratios to predict strength performance is not a new idea. Keogh, Hume, Mellow, & Pearson (2009) conducted a study evaluating levels of strength of powerlifters. The conclusion the researchers found was that greater levels of muscular hypertrophy is important to achieving superior

performance. Although a different approach of assessing the impact of anthropometrics when it comes to body proportionality and performance, the concept of ascertaining understanding of performance outcomes is the same. A notable difference between the two studies is that there is more ways to control dimensions of muscular mass than the ratios outlined in the present study.

User Dependent Plasticity

Another potential cause for why there was no significant relationship between anthropometrics and the dependent variables is the idea of user dependent plasticity. The subjects' high level of training and experience may have washed out any relationship that anthropometric ratios may have had on kinematic and kinetic outcomes. The user dependent plasticity concept states that the repetition of movements will produce improvements in performance and "plasticity of the motor cortex" (Butefisch, Davis, Wise, Sawaki, Kopylev, Classen, & Cohen, 2000; Mawase, Uehara, Bastain, & Celnik, 2017). This subject pool had at least two years of experience in the back squat exercise to be included in the study. These individuals regularly and repeatedly performed the back squat, and over time, developed "motor memories" that improved the performance of the squat, which allowed that to become skilled in performing the maneuver (Mawase et al, 2017). This study indicated that there is no relationship amongst the anthropometric ratios of the subjects and the back squat. That does not mean, however, that there never has been a relationship as one

may have been present prior to engaging in the back squat exercise and that the motor learning that has occurred over time aided to eliminate the relationship.

Power

Power is the rate of work production, where work is divided by the amount of time that the work was being done (Hall, 2015). These results suggest that there was a significant difference in the amount of power in the hip between the left and right side in the sagittal and transverse planes, where a greater contribution of power came from the right hip. Participation in the back squat is intended to enhance performance uniformly across all musculature, including power in the hip. Muscular strength and movement speed impact power results, so the result of significant power difference in the left and right hip is concerning (Hall, 2015). The lack of symmetry may have adverse impacts on performance, and more importantly, may increase the risk of injury. The greater power contributions to the right side may cause overuse in the musculature of the right side as compensatory patterns develop (Ebrahmi, Kamali, Razeghi, & Haghpanah, 2017). These patterns may impact the technique expected during performance in sport, for example. Also, the deficit in the left side may become problematic when lifting heavy loads as the strain on the left side may not be able to withstand the same strain on the right. These different thresholds may increase the risk of injury to participants.

Abduction

In the frontal plane, there was a significant difference in the angle measure when comparing the levels of abduction between the left and right hip. The instructions for the back direct that there is a simultaneous movement in the hip (Baechle & Earle, 2008). This is important because when training occurs for performance enhancement, the goal is to train both sides equally regardless of side dominance. The significant difference indicates more range of motion on the right hand side in the frontal plane. This range of motion may develop the right hand side's range of motion more than the left, which may be left underdeveloped relative to the subject's hip. The subject may have undesirable compensatory motor control strategies that may impact other movements, such as walking, running, and jumping (Ebrahimi et al, 2017; & Newtown, Gerber, Nimphius, Shim, Doan, Robertson, Pearson, Craig, Hakkinen, & Kraemer, 2006). This difference in range of motion was not detected during the prescreens, which were all performed without an external load. This suggests that a load of 80% of 1 RM may be a heavy enough load to alter the kinematics of subject's back squat performance. Since kinematics factor into the inverse dynamics, this suggests that kinetic results may be impacted as well.

Force

The final significant data point that was found in the left and right hip comparison of the force in the frontal plane. The force in the frontal plane indicates medial forces in both the left and right side, with more force found in the right side

compared to the left side. This imbalance is undesirable as asymmetry indicates different muscle fiber recruitment patterns when comparing the two sides. This may lead to varied training adaptations, which does not coincide with the goals of why one would perform the back squat. Subjects engage in the back squat to develop both sides of their musculature evenly, and that should be reflected in the force results (Baechle & Earle, 2008; Shoenfeld, 2010).

Side dominance is a concern for participants in the back squat, whether it is in a strength & conditioning setting, rehabilitation setting, or in daily life because imbalances in range of motion as determined by kinematic results, or force results from kinetics, researchers are concerned that the dominance of one side over another (in the case of the present research, the right side) may increase the risk of injuries and impede training adaptations that should be gained for performance enhancement purposes.

Future Recommendations

The results presented in this study are just the beginning of a large investigation into the question of the impact of body proportionality on resistance training. There are many more questions that need to be answered with regards to the hip. For example, the electromyographic (EMG) data on the gluteus maximus warrants investigation to see if those results show similar findings of non-significance that were found when analyzing the anthropometric ratios. Additionally, left and right side comparisons should be done to see if significant differences are present and where those differences are. The gluteus maximus is a large muscle and an agonist muscle of the hip complex, so it makes sense to evaluate the muscle activation patterns of the hip during the back squat exercise (Baechle & Earle, 2008; Hall, 2015; & Schoenfeld, 2010).

Spine, Knee, and Ankle

The back squat is a complex, full body exercise, and each joint that is involved in the movement needs to be investigated. The results of the spine, knee, and ankle need to be analyzed to see if a relationship exists between the anthropometric ratios and the kinematic, kinetic, and EMG outcomes. All the complexes needed to be analyzed individually first, and then, where appropriate, can be used as comparative data points when discussing the movement in various parts or as a whole.

The back squat is one exercise of many that can be used to develop the lower extremities and offers benefit to the upper body. It is logical that the same analysis should be done on the spine, hip, knee, and ankle as it relates to anthropometric ratios and left & right side comparisons when assessing kinematic, kinetic, and EMG outcomes of the straight bar deadlift and hex bar deadlift. One of the intents of the present study was to see if certain individuals are at a higher risk of injury due to their anthropometric ratios when performing the back squat. For example, if hip force was seen to increase with one of the ratios, we would identify that as a possible marker for injury. If an individual was identify as such a case, their training program would be modified. Researchers would need to know how the response would differ, if at all, for other exercises, before making those recommendations. The straight bar deadlift and hex bar deadlift are two exercises that share enough components that they may be appropriate alternatives, while being distinctively different than the back squat.

Recruitment Strategy

Future research needs to consider the subjects that are participating in the study. One way to modify the subject pool is to change the recruitment strategy of the research. The reason for this change to evaluate other subjects comes from the results of the power analysis. The G*Power results of the present study point to an unfeasible amount of subjects needed to satisfy the .80 power threshold. There are many logical alterations to the strategy that make sense. First, a follow-up study should focus on recruiting subjects that have greater variability in the hip width to

height and torso to height ratios. Specifically, subjects that are two standard deviations above and below the mean or more should be recruited and their results should be assessed to see if a relationship exists with the anthropometric ratios. Second, it appears that the level of experience may have had an impact on the results. It would be advised to run a similar study with a group of beginner/novice back squatters, and compare their results to the more experienced group.

As previously stated, the back squat is an exercise that is utilized by many people at different levels of training. For example, it would be beneficial to capture the same outcomes under the same experimental protocol of novice or beginner lifters. Even better, conduct a longitudinal study over two years, and take a group of beginners and compare their pre and post test results and see if a relationship is present in the beginning and then goes away. This would address the user-dependent plasticity concept. Additionally, a study on women would add tremendous context to the research because women have different squat kinematics than males. The comparison of the results of females under the same conditions to men would help to identify some of the commonalities and differences that may be present, especially to anthropometrics. The research indicates that squat mechanics are different between the genders because females have a wider pelvic girdle than males (Graci, Van Dillen, & Salsich, 2012; Lessi, dos Santos, Batista, de Oliveira, & Serrao, 2017). As it relates to this study, the hip width to height ratio may render varied results. Lastly, the issue of side dominance showed that there were differences in some cases, but to

better understand those differences it would make sense to recruit more left dominant subjects as the present study was ninety percent right hand dominant (18 out of 20 subjects).

Conclusion

The present research intended to explore if a relationship was present between anthropometric ratios and kinematic and kinetic outcomes from the hip during the back squat. The goal was to evaluate data that might lend to answering more broad questions about risk of injury and performance as it relates to the very popular, but highly complained about back squat (Chandler & Stone, 1992; List et al, 2010; & Schoenfeld, 2010). Although the present study determined that a relationship between the ratios and squat outcomes did not exist, the study did unveil interesting trends.

It appears that the hip complex does not have a relationship with anthropometric ratios that represent vertical and horizontal components of the human body with respect to overall height. Importantly, this trend pertains to this well trained group of subjects that have limited variability in their anthropometric ratios and others that would fit their profile. The subjects that constituted the sample for this back squat study self-selected into the study because they are good to very good at the exercise and they perform the movement on a regular basis. The unfortunate result of the subjects is that they lacked variability when it came to their anthropometric ratios.

The issue of side dominance became a major focus of discussion because significant differences were found in the left and right side of hip in four places. This differences were unexpected because symmetry across the exercise was instructed

and expected (Baechle & Earle, 2008). Due to the differences, questions about the impact on injuries and performance arose. The issue of side dominance is one that needs to be explored further because the presence of imbalances in kinematic and kinetic outcomes could have adverse effects on the squat performer's health and impede their performance enhancement.

The concept of user dependent plasticity has extreme relevance on the present study because the subjects were well trained, which meant that they had many experiences that shaped the organization of the neuron connections that developed movement strategies (Butefisch et al, 2000). The modifications over time may have eliminated the relationship that previously may have been present. This is important because it tells us that responses will vary based on training experiences and how impactful motor learning can be.

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Appendix A

Institutional Review Board Approval



EXPEDITED REVIEW APPROVAL

To: [Jay Garrels](#)

CC: There are no items to display

Re: Study# [Pro2016-0332](#)

Anthropometric ratios and their correlation to kinematic, kinetic, and EMG measures.

Study Expiration Date: 9/7/2017 .

This is to advise you that the above Study has been presented to the Institutional Review Board for expedited review.

Please be reminded that all modifications to approved projects must be reviewed and approved by the Institutional Review Board before they may be implemented. Any changes to this protocol must be submitted for IRB approval before initiated.

All serious adverse events and unexpected adverse events must be reported to Institutional Review Board within seven days.

Please do not make any changes to the IRB approved consent without approval of the IRB. Only the IRB stamped approved consent should be used.

If your study meets the definition of a qualifying study that meets the FDAAA 801 definition of an "applicable clinical trial", you are responsible for ensuring that the trial has been registered

properly on the Clinical Trials.gov website prior to the enrollment of any subject.

"Applicable clinical trials" generally include controlled clinical investigations, other than phase 1 clinical investigations (with one or more arms) of FDA-regulated drugs, biological products, or devices, that meet one of the following conditions:

The trial has one or more sites in the United States

The trial is conducted under an FDA investigational new drug application or investigational device exemption

The trial involves a drug, biologic, or device that is manufactured in the United States or its territories and is exported for research

For complete statutory definitions and more information on the meaning of "applicable clinical trial," see [Elaboration of Definitions of Responsible Party and Applicable Clinical Trial \(PDF\)](#).

This study has been reviewed and approved via expedited review on 9/8/2016.

Documents approved:

Protocol
Consent form
Lift Questionnaire
Phone Screen
Physical Activity Readiness Questionnaire
Recruitment Flyer
Squat Cool down script
Warm-up script
Data collection form

HIPAA Authorization is required.

Important news about our email communications.

Hackensack Meridian Health Network has implemented secure messaging services. If you need assistance with retrieving a secure email, please send an e-mail to postmaster@hackensackmeridian.org

Confidentiality Notice:

This e-mail message and any attachments from Hackensack University Medical Center are confidential and for the sole use of the intended recipient. This communication may contain Protected Health Information ("PHI"). PHI is confidential information that may only be used or disclosed in accordance with applicable law. There are penalties under the law for the improper use or further disclosure of PHI. If you are not the intended recipient of this e-mail or the employee or agent responsible for delivering the communication to the intended recipient, then you may not read, copy, distribute or otherwise use or disclose the information contained in this message. If you received this message in error, please notify us by telephone at 551.996.2000 or by e-mail to postmaster@hackensackmeridian.org. Please indicate that you were not the intended recipient, and confirm that you have deleted the original message. Please do not retransmit the contents of the message. Thank you. Hackensack Meridian Health Network is the proud recipient of Quality New Jersey's Governor's Gold Award for Performance Excellence

Appendix B
Recruitment Flyer

Squatters and Deadlifters WANTED!!!



(Catanzaro, 2015; Merritt, 2016)

Professor Jay Garrels in the Department of Interprofessional Health Sciences and Health Administration in the School of Health and Medical Sciences and is conducting a study on the impact of anthropometric length ratios on the back squat and hex bar deadlift.

Information from this study may help in our understanding the appropriateness of certain individuals to participate in these exercises.

Your participation is completely voluntary, and your identity will be kept strictly confidential, with all personal data kept in a coded form.

Interested? Contact: Professor Garrels at jay.garrels@shu.edu.

Appendix C

Informed Consent Form & HIPAA Form



Consent approved via expedited on 9/8/2016
Expiration Date: 9/7/2017

Hackensack University Medical Center & Seton Hall University

Consent Form

Title of Protocol

Anthropometric ratios and their correlation to kinematic, kinetic, and electromyographic measures in the back squat, deadlift, and hex bar deadlift exercises.

Who is conducting this study?

This study is being conducted by Jay Garrels, MS. Professor Garrels is an adjunct faculty member teaching Graduate Exercise Physiology and Nutrition; additionally, he is a fourth year doctoral student conducting research in accordance with his dissertation.

This research is being conducted at Seton Hall University, South Orange, NJ.

Why have I been asked to take part in this research study?

You have been asked to take part in this study because you have self-identified as a potential participant and because you are a healthy, physically active male between the ages of 18 and 50, have a minimum of two years experience performing the back squat, deadlift, and hexbar deadlift exercises, and you are free of musculoskeletal injuries within the previous six months.

It is up to you to decide whether or not to take part in this study. Please read this entire consent form. This consent form may contain words that you do not understand. Please ask the study doctor or the study staff to explain any words or information that you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

Why is this study being conducted?

The goal of this study is to investigate whether or not there is a relationship between the length of certain body parts and the performance of recreational, male athletes participating in the back squat, deadlift, and hex bar deadlift.

How many people will participate in this study?

Approximately 20 healthy, male recreational athletes will be participating in this study.

What is involved in this study?

You will be asked to clear three prescreens prior to participating in the study. The three prescreens are a physical activity readiness questionnaire (PAR-Q), a stability test, and a body mass index screen (BMI). The PAR-Q requires you to answer a series of questions related to your health and your ability to perform activities. The stability test assesses your ability to show stabilization and balance, which is important for properly executing the exercises. The BMI is a measure of body fat based on height and weight. You will need to wear tight fitting clothing for the study. This is because the cameras need a clear field of vision that loose clothing can obstruct. Also, 8 wireless EMG sensors and 39 reflective markers will be attached to your body with double-sided adhesive tape.

You will be lead through a five minute warm-up that includes standard stretches that an individual would perform if they were participating in a resistance exercise routine. You will perform five sets of one repetition for each exercise. You may take a break whenever you need one plus breaks are included between each set. Additionally, after the resistance exercises are completed, you will be lead through a five minute cool-down that includes standard stretches that are normally performed after working out. Also, for both the warm-up and cool-down, you will be granted as much time as you need to stretch on your own.

You will be asked to perform five trials of one repetition for each of the following exercises: back squat, deadlift, and hex bar deadlift. The order of the exercises are randomized and will be assigned to you on the day of your testing. Each repetition will be performed at 80% of your maximum performance. For example, if your maximum repetition was 200 pounds, you would be performing a single repetition at 160 pounds.

How long will I be in the study?

This study only requires you to visit the Biomechanics Lab on Seton Hall University's campus once. The duration of the visit will be approximately 90 minutes.

What are the risks involved in this study?

The risks associated with this study are the same risks that you have when you perform these exercises on your own. With all resistance training exercises, such as the lifts that are to be performed in this study, there is a potential risk of injury. The risks associated with lifting activities are mitigated in this study because you are supervised at all times, you are being tasked with performing these exercises with a moderate effort (not maximal), and you also have the ability to stop the testing at any time.

Are there benefits to taking part in the study?

The information gathered in this study may assist in developing a better understanding of how certain limb lengths of body parts impact the performance of the back squat, the deadlift, and the hex bar deadlift. This information can be beneficial to you, other athletes, and strength and conditioning coaches because it can influence how exercise is prescribed, and possibly aid in the understanding of how to better improve performance and decrease the risk of injury.

What other options are there?

There are no other options available at this time. Your alternative option is to not participate in the study.

How will information about me be kept private?

Your identity and participation are confidential to the extent permitted by law. If investigational drugs and/or medical devices subject to U.S. Food and Drug Administration regulation (FDA) are involved, however, it may be necessary for this consent form and other medical records to be reviewed by representatives of the FDA. In addition the sponsor (list the name of the sponsor), representatives of the sponsor, the Director of Research or designee, or the Institutional Review Board will be granted direct access to your original medical records for verification of clinical trial procedures and/or data without violating your confidentiality to the extent permitted by applicable laws and regulations. By signing this consent you or your legally acceptable representative is authorizing such access.

Records identifying you will be kept confidential to the extent permitted by applicable law. If the results of the trial are published your identity will remain confidential.

Furthermore, your data will be kept in coded form on a flash drive in a locked cabinet.

What are the costs?

There are no costs to you to participate in this study. Additionally, you will be compensated with a \$25USD gift card for your participation in the study.

What are my rights as a research participant?

Your decision to take part in this study is voluntary. If you decide not to participate or if you choose to withdraw after beginning the study, you will not lose any benefits associated with your medical care. You are encouraged to ask questions before deciding whether you wish to participate and at any time during the course of the project. Your participation may be terminated by the investigator or sponsor without regard to your consent. You will be told of any new findings that may influence your decision to continue to participate in this research project. If information becomes available that may influence your decision to take part in this study you will be asked to sign a revised consent or consent addendum. This will be at the discretion of the

Institutional Review Board. In the case of physical injury resulting from participation in the study, treatment determined by a physician will be made available to you. This care will be billed to you/your insurance company in the usual and customary manner. In the very unlikely event that you were to be injured as a result of your participation in this study, you would be solely responsible for the costs of any medical treatment, insurance deductibles, loss of wages, legal fees, and/or any other associated hardship. A \$25 gift card will be provided to you for your participation in the study.

Who can I call if I have questions or problems?

For questions concerning this research project and/or research subjects' rights, you should call The Research Integrity Office at 551-996-2255. In the event that medical assistance is required, you are instructed to call Jay at (603 491 0585). If immediate medical assistance is required, call 911.

Financial Disclosure

The Principal investigator is not receiving payment from the study sponsor for his for his participation in this protocol. There are no related parties that have any financial interest in the outcome(s) of the present study.

If you have questions about this disclosure please call the Research Integrity Office at (551) 996-2255.

Consent

- I have read this consent form or it has been read to me.
- All of the questions that I had were answered to my satisfaction.
- I have been told that I will receive a signed copy of this consent form for my records.
- By signing this consent form I have not waived any of the legal rights which I otherwise would have as a participant in a research study.

I hereby consent to participate.

Subject's Name		
_____	_____ / _____	
Signature of Subject	Date	Time

Name of Legally Authorized Representative <i>[when applicable]</i>		
_____	_____ / _____	
Signature of Legally Authorized Representative <i>[when applicable]</i>	Date	Time

Name of Person Conducting Informed Consent Discussion		
_____	_____ / _____	
Signature of Person Conducting	Date	Time

Informed Consent Discussion

[Include only for limited or non-readers]

If this consent form is read to the subject because the subject (or legally authorized representative) is unable to read the form, an impartial witness not affiliated with the research or investigator must be present for the consent and sign the following statement:

I confirm that the information in the consent form and any other written information was accurately explained to, and apparently understood by, the subject (or the subject's legally authorized representative). The subject (or the subject's legally authorized representative) freely consented to be in the research study.

_____	_____ / _____
Signature of Impartial Witness	Date Time



IRB # Pro2016-0332

HACKENSACK UNIVERSITY MEDICAL CENTER

**AUTHORIZATION TO USE OR DISCLOSE PROTECTED HEALTH INFORMATION
FOR A RESEARCH STUDY**

I authorize use or release of the information described below.

Patient Name	Date of Birth	
Address (Street, City, State, Zip Code)		Telephone Number
The information may be released by: Hackensack University Medical Center, Jay Garrels, and his associates involved in the Anthropometric ratios as a predictor in kinematic, kinetic, and EMG measures in recreational male athletes performing a back squat, deadlift, and hex bar deadlift research study.		
This information may be released to: No health information will be released.		
Treatment dates: Utilizing the Physical Activity Readiness Questionnaire (PAR-Q), health status will be evaluated.	Purpose of Request: Purpose of the research is to assess anthropometric ratios as a predictor of performance, and potentially, risk of injury in the back squat, deadlift, and hex bar deadlift	
The following information is to be released: Data collected from the study will be released with no identifying links to the individual participants of the study.		
Sensitive Information: I understand that the information in my record may include information relating to sexually transmitted diseases, acquired immunodeficiency syndrome (AIDS), or infection with the Human Immunodeficiency Virus (HIV). It may also include information about behavioral or mental health services or treatment for alcohol and drug abuse.		
Right to Revoke: I understand that I have the right to revoke (or cancel) this authorization at any time. I understand if I revoke this authorization I must do so in writing. I understand that the revocation will not apply to information that has already been released based on this authorization.		
Expiration: Unless otherwise revoked, this authorization will expire at the end of the research study. (Or, unless otherwise revoked, this authorization has no expiration date.)		
Redisclosure: I understand that my information may be re-released by the organization that receives it, and the information may no longer be protected by federal confidentiality rules.		
Other Rights: I understand that authorizing the disclosure of this health information is voluntary. I can refuse to sign this authorization. I do not need to sign this form to assure treatment. However, since this authorization is needed for participation in a research study, my enrollment in the research study may be denied.		
I understand that I may inspect or obtain a copy of the information to be used or disclosed, as provided in CFR 164.524.		
If I have any questions about the use or release of my health information, I can contact Jay Garrels at 973 275 2401.		
Signature of Research Subject or Legally Authorized Representative		Date
If Signed by Legally Authorized Representative, Relationship to Research Subject		Date

Received and filed by IRB on 9/8/2016 by: LR

Version Ia 04/03

Application packet version 06/03, rev. 01/12

Appendix D

Physical Activity Readiness Questionnaire (PAR-Q)

Data Collection Sheet

NAME: _____ DATE: _____

HEIGHT: _____ in. WEIGHT: _____ lbs. AGE: _____

PHYSICIANS NAME: _____ PHONE: _____

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

	Questions	Yes	No
1	Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?		
2	Do you feel pain in your chest when you perform physical activity?		
3	In the past month, have you had chest pain when you were not performing any physical activity?		
4	Do you lose your balance because of dizziness or do you ever lose consciousness?		
5	Do you have a bone or joint problem that could be made worse by a change in your physical activity?		
6	Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?		
7	Do you know of <u>any</u> other reason why you should not engage in physical activity?		

If you have answered "Yes" to one or more of the above questions, consult your physician before engaging in physical activity. Tell your physician which questions you answered "Yes" to. After a medical evaluation, seek advice from your physician on what type of activity is suitable for your current condition.

Supplemental Questions:

- i. How many years of experience do you have with the back squat, deadlift, and hex bar deadlift?

- ii. When was the last time you performed the back squat, deadlift, and hex bar deadlift?

- iii. What was the maximum weight and how many reps did you perform at that weight for each exercise (back squat, deadlift, and hex bar deadlift)?

Appendix E
Overhead Squat Test



NAME: _____ **DATE:** _____

Overhead Squat Test										
Anterior View		Right YES	Left YES	Lateral View (Right Side)		YES	Posterior View		Right Yes	Left YES
Foot	Foot Turns Out			L-P-H-C	Excessive Forward Lean		Foot	Heel of Foot Rises		
Knee	Moves Inward				Low Back Arches			Foot Flattens		
	Moves Outward				Low Back Rounds		L-P-H-C	Asymmetrical Weight Shift		
				Upper Body	Arms Fall Forward					
MODIFIED:		HEELS ELEVATED				ARMS DOWN				
FEET										
KNEES										
LPHC										
UPPER										
NOTES:										

Appendix F

Instructor's Warm-up Script

Warm up Script

00:00 “Please follow my lead as we will warm-up prior to exercising”

Place your Right foot in your left hand

00:15

Place your left foot in your right hand

00:30

Right foot over left foot, slight bend in the knees, reach for your toes

00:45

Left foot over left right, slight bend in the knees, reach for your toes

1:00

On your butts, bring both feet into center, push down on your knees with your elbows, stretch groin

1:15

Extend right foot out, pull left foot in, reach for your right toe

1:30

Extend left foot out, pull right foot in, reach for your left toe

1:45

On your feet, spread your feet more than shoulder width apart and reach for center

1:50

Reach to your right

1:55

Reach to your left

2:00

Find a wall, push against the wall, straddle your feet with the right one back and stretch your calf muscles

2:15

Push against the wall, straddle your feet with the left one back and stretch your calf muscles

2:30

Standing upright, extend your arms to the side and begin to loosen your arms and shoulders by doing forward arm circles, start small and work into making bigger circles

2:45

Standing upright, extend your arms to the side and begin to loosen your arms and shoulders by doing backward arm circles, start small and work into making bigger circles

3:00

For 15 seconds, you will run in place.

3:15

Standing upright, pull your right knee into your chest.

3:30

Standing upright, pull your left knee into your chest.

3:45

You will now perform a countermovement jump 5 times.

4:00

You now have six minutes to stretch and warm-up on your own, testing will begin at the conclusion of the stretch/warm-up time. Begin...

Appendix G
Exercise Instructions

Back Squat Instructions (NSCA Guidelines)

- Grasp the bar with a closed, pronated grip with hands slightly further than shoulder width apart
- Step under the bar and position the feet parallel to each other
- Place the bar in a balanced position on the upper back
- Lift the elbows up to create a “shelf” for the bar using the upper back and shoulder muscles
- Hold the chest up and out
- Tilt the head up slightly
- Once in position, lift the bar off the supports (a spotter was in position to assist the subject)
- Extend the hips and knees to lift the bar
- Take one or two steps backward to ensure that you have one foot on each of the force plates
- Position the feet should-width apart, and ensure they are even with each other
- All repetitions begin and end from this position
- Maintain a position with a flat back, elbows high, and the chest up and out
- Allow the hips and knees to slowly flex while keeping the torso-to-floor angle relatively constant
- Keep the heels on the floor and the knees aligned over the feet

- Continue flexing the hips and knees until the thighs are parallel to the floor, the trunk begins to round or flex forward, or heels rise off the floor
- Maintain a position with flat back, high elbows, and the chest up and out
- Extend the hips and knees at the same rate
- Keep the heels on the floor and the knees aligned over the feet
- Do not flex the torso forward or round the back
- Continue extending the hips and knees to reach the starting position
- At the end of the set, step forward to the rack
- Squat down until the bar rests on the supports

Appendix H
Cool-down Script

Cool-down Script

00:00 “Please follow my lead as we will cool-down”

Place your Right foot in your left hand

00:15

Place your left foot in your right hand

00:30

Right foot over left foot, slight bend in the knees, reach for your toes

00:45

Left foot over left right, slight bend in the knees, reach for your toes

1:00

On your bottoms, bring both feet into center, push down on your knees with your elbows, stretch groin

1:15

Extend right foot out, pull left foot in, reach for your right toe

1:30

Extend left foot out, pull right foot in, reach for your left toe

1:45

On your feet, spread your feet more than shoulder width apart and reach for center

1:50

Reach to your right

1:55

Reach to your left

2:00

Find a wall, push against the wall, straddle your feet with the right one back and stretch your calf muscles

2:15

Push against the wall, straddle your feet with the left one back and stretch your calf muscles

2:30

Standing upright, extend your arms to the side and begin to loosen your arms and shoulders by doing forward arm circles, start small and work into making bigger circles

2:45

Standing upright, extend your arms to the side and begin to loosen your arms and shoulders by doing backward arm circles, start small and work into making bigger circles

3:00

You now have three minutes to stretch and cool-down on your own.

At the end of three minutes, the cool-down session will conclude.

Appendix I Phone

Screen Script

Phone Screen Script

The following will be spoken to the subject over the phone:

“Hello- my name is Jay Garrels and I am a doctoral student in the Department of Interprofessional Health Sciences and Health Administration and I am conducting a study on anthropometric ratios, which are measurements of the human body, and their potential relationship with outcomes related to the back squat, deadlift, and hex bar deadlift.

Information from this study may help in our understanding of possible better practices when implementing resistance training protocols.

Participation requires only one visit to the motion analysis lab in Corrigan Hall Room 67 on Seton Hall University’s campus for approximately two hours. There are a couple of prescreens that will be conducted first to make sure you are eligible for the study. The prescreens are a physical activity readiness questionnaire, a BMI test, overhead squat, and a stability test. If you pass the prescreens, you will be moved into the study. At the end of today’s phone call, I will ask you for your height, weight, and a series of health related questions. You will wear bike shorts, a tight fitting top, and tennis shoes (or athletic footwear you would wear in a gym) throughout the testing session. The shorts and top will be provided, however, you may bring your own, if you would like. In a private room, eight electrodes, measuring the electrical activity in your muscles will be attached to the ankle, calf, and hip regions of both the left and right leg. The electrodes do not disseminate an electrical charge, rather they record the charge that is already present in the muscle. This will be done in private space by a trained clinician who has clinical experience. You will be instructed on a warm-up. You will be also given personal time to warm-up as you see fit. You will tell me when you are sufficiently warmed up. Once you are warmed up, maximum voluntary contractions, also known as MVCs, will be gathered. Simply, you will be pushing against resistance as hard as you can. After the MVCs are gathered, 41 reflective markers will be placed all over your body. These special markers help the motion analysis cameras track your movement. Next, you will participate in the actual testing. The testing involves three resistance exercises: the back squat, deadlift, and hex bar deadlift. The exact order of the lifts will be given to you at the testing. You warm up for each exercise and be given breaks between each repetition. You will be asked to perform 1 repetition of your 80% of 1 RM load. Most people can perform 10 repetitions at this load. You will be asked to perform a single repetition for each trial. You will perform five trials for each exercise. After your last repetition of your last exercise, you will be lead through a cool-down.

Your participation is completely voluntary, and your identity will be kept strictly confidential, with all personal data kept in a coded form. If you decide to participate, you must refrain from resistance exercises for 24 hours prior to the data collection.

I hope you are interested in participating in this study. I would now like to give you the opportunity to ask any questions about the study that you might have.”

Appendix J
Overhead Squat Test Amendment



EXPEDITED REVIEW APPROVAL

To: [Jay Garrels](#)

CC:

From: [Cheryl Fittizzi, RN, CIP](#)

Re: Amendment for Study# Pro2016-0332 Anthropometric ratios and their correlation to kinematic, kinetic, and EMG measures.

Amendment #: Ame2_Pro2016-0332

Study Expiration Date: 9/7/2017

This is to advise you that the above Amendment has been presented to the Institutional Review Board for expedited review.

Please be reminded that all modifications to approved projects must be reviewed and approved by the Institutional Review Board before they may be implemented. Any changes to this protocol must be submitted for IRB approval before initiated.

All serious adverse events and unexpected adverse events must be reported to Institutional Review Board within seven days.

If your study meets the definition of a qualifying study that meets the FDAAA 801 definition of an "applicable clinical trial", you are responsible for ensuring that the trial has been registered properly on the Clinical Trials.gov website prior to the enrollment of any subject.

"Applicable clinical trials" generally include controlled clinical investigations, other than phase 1 clinical investigations (with one or more arms) of FDA-regulated drugs, biological products, or devices, that meet one of the following conditions:

- The trial has one or more sites in the United States

 - The trial is conducted under an FDA investigational new drug application or investigational device exemption

 - The trial involves a drug, biologic, or device that is manufactured in the United States or its territories and is exported for research

For complete statutory definitions and more information on the meaning of "applicable clinical trial," see [Elaboration of Definitions of Responsible Party and Applicable Clinical Trial](#) (PDF).

Please do not make any changes to the IRB approved consent without approval of the IRB. Only the IRB stamped approved consent should be used.

This amendment has been reviewed and approved via expedited review on 11/22/2016.

The prescreen is a simple assessment called the Overhead Squat Test. The tests calls for the subject to perform a non-weight bearing squat maneuver with his hands over his head. His performance is assessed based on standards set forth by the National Academy of Sports Medicine (NASM). The test is used to evaluate human movement of the maneuver, flexibility, and tightness of the muscles. Supporting documents are attached.

Important news about our email communications.

Hackensack Meridian Health Network has implemented secure messaging services. If you need assistance with retrieving a secure email, please send an e-mail to postmaster@hackensackmeridian.org

Confidentiality Notice:

This e-mail message and any attachments from Hackensack University Medical Center are confidential and for the sole use of the intended recipient. This communication may contain Protected Health Information ("PHI"). PHI is confidential information that may only be used or disclosed in accordance with applicable law. There are penalties under the law for the improper use or further disclosure of PHI. If you are not the intended recipient of this e-mail or the employee or agent responsible for delivering the communication to the intended recipient, then you may not read, copy, distribute or otherwise use or disclose the information contained in this message. If you received this message in error, please notify us by telephone at 551.996.2000 or by e-mail to postmaster@hackensackmeridian.org. Please indicate that you were not the intended recipient, and confirm that you have deleted the original message. Please do not retransmit the contents of the message. Thank you. Hackensack Meridian Health Network is the proud recipient of Quality New Jersey's Governor's Gold Award for Performance Excellence

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